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DIRECTORATE OF WEAPONS AND ENGINEERING RESEARCH

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VEHICLE MOBILITY RESEARCH PARRY SOUND – 1966

(Revised)

Submitted by

Organic and Associated Terrain Research Unit

McMaster University, Hamilton, Ontario

ER REPORT NO. 2/67

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OTTAWA

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A Report to the Defence Research Board
by the
Organic and Associated Terrain Research Unit
McMaster University, Hamilton, Ontario

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FOREWORD

The Organic and Associated Terrain Research Unit (OATRU) of McMaster University, Hamilton, Ontario is an interdisciplinary organization set up to study problems connected with muskeg (organic terrain) and the environments in which muskeg occurs. To date its work on off-road vehicle mobility and terrain trafficability conducted with Defence Research Board (1, 2, 3) and the US Army Corps of Engineers (4) has qualitatively and quasi-quantitatively covered a broad spectrum of vehicle behavior and terrain conditions on muskeg and associated terrain. The mobility and trafficability problems studied have been mainly to determine "go-no-go" conditions, with some additional interest in fuel consumption rates, drawbar pull-slip, and pressure cell measurements. However, knowledge is still deficient in the area of quantitative relations between terrain-vehicle characteristics and trafficability-mobility in muskeg and associated terrain. The purpose of this report is therefore to examine that deficiency.

The term trafficability may be thought of as being the ability of the soil or its vegetal cover to withstand repeated vehicle passes, whereas mobility can be defined as the ease with which a vehicle surmounts the obstacles offered by terrain. For the purpose of the report, one may consider that trafficability and mobility each depend on both the terrain characteristics and the vehicle characteristics simultaneously, and therefore must always be considered together.

In order to compare effectively the mobility of two vehicles operating on one type of terrain, or the trafficability of two types of terrain with respect to one vehicle, it is necessary to be able to measure in quantitative terms, the vehicle characteristics contributing to mobility and the terrain characteristics that may affect trafficability.

Terrain factors controlling mobility and trafficability in muskeg can and have been classified and described (5). The low bearing capacity of some types of muskeg is of course a factor of major importance.

On this basis the following objective was aimed for, that is: "To determine quantitatively the interrelation between terrain-vehicle characteristics and mobility and trafficability on soft muskeg (low bearing capacity)".

More specifically this was broken down into the following components. These were:

1. To record the vehicle design features of several tracked vehicles similar in configuration but differing in dimensions. The design features recorded were:
   - (a) track length,
   - (b) track width,
   - (c) vehicle weight, center of gravity location,
   - (d) number of road wheels.
2. To measure the terrain characteristics in the muskeg in areas with E, F, and I cover in various combinations. The characteristics measured were:
   - (a) cover type,
   - (b) peat type,
   - (c) peat depth,
   - (d) peat density,
   - (e) peat moisture content,
   - (f) quantitative peat and mat classification and description.
3. To measure vehicle performance while operating in the areas noted in (2) above, measured at various numbers of vehicle passes. The performance characteristics measured were:
   - (a) drawbar pull,
   - (b) slip,
   - (c) speed,
   - (d) trim angle,
   - (e) amplitude of pressure variation along track length at very low speed,
   - (f) torque output at sprocket.
4. To record:
   - (a) rolling resistance,
   - (b) sink, rate of sink under a passing vehicle, and final sinkage,
   - (c) the rate of sink under a standard load.
5. To attempt to establish quantitative relations between the terrain-vehicle characteristics and terrain-vehicle performance listed above so that a basis ("model") for prediction can be developed. The relations that were considered were that:
   - (a) Sinkage (for a standard load) rate is proportional to water content.
   - (b) Net sinkage for a standard static load is proportional to diameter and number of woody and non-woody fibers in the mat.

(c) Rolling resistance is proportional to sinkage, weight of vehicle, mean ground pressure of vehicle, number of road wheels, track width, pressure variation amplitude along track length.

(d) There is a relation between drawbar pull, slip, and muskeg type.*

This report is therefore an account of the extent to which these objectives have been met. It is also hoped that it will serve as a guide to the direction in which possible future mobility research in muskeg should be channeled.

The Organic and Associated Terrain Research Unit at McMaster University is grateful for the assistance and co-operation of the Army Equipment Engineering Establishment (AEEE), Orleans, and for the financial support provided by the Defence Research Board.

* *As defined by the Radforth classification system (6).*

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PERFORMANCE OF TRIALS

To facilitate work towards the objectives outlined in the foreword, a Plan of Test was prepared and is included in its original form in the report as Appendix I. The sections of the report dealing with Terrain Selection, Vehicle Description, and Measurement Techniques and Observations will reveal the extent to which it was possible to adhere to this plan in the performance of the trials.

TERRAIN SELECTION

In accordance with the objectives outlined in the Plan of Test (Appendix I), it was necessary to select and obtain the use of several muskeg areas with EI and FI cover (6) with a variety of water tables and moisture contents. It had been decided at an early date among the parties involved in the project that the work would be conducted near Parry Sound, Ontario. Previous vehicle projects had been conducted here and, in addition to the known suitability of muskeg areas, it has convenient facilities for vehicle maintenance, personnel accommodation, and supply.

It was decided by the project manager that a minimum of six test areas would be required for this project, as it was necessary to find EI and FI cover in each of low, medium, and high moisture contents. From a general knowledge of the area and from 5000-ft. air photographs, several possibilities were selected for closer inspection.

Early in May 1966, a short aerial reconnaissance was undertaken to obtain low-altitude oblique photographs of likely test sites and to gain an appreciation of the approximate water contents of these areas. The choice was then reduced to about eight areas, which were inspected and photographed on foot.

The result of this survey was the decision to work in six test areas, which are named and briefly described in Table I below, and are described in more detail in Appendix II – Terrain Description. The names used to designate the test areas are in some cases local names and, in others, are numbers that have been used in previous projects.

TABLE I – Designation of Test Areas

Area Name	*Cover*	*Moisture Content*
Thousand Acre Bog	EI	High
10A	EI	Medium-Low
Woods	EI	Low
Thousand Acre Bog	FI	High
66-1	FI	Medium
7	FI	Low

The oblique aerial photographs contained in the appendix will give a general impression of the muskeg conditions involved, and the reader will possibly acquire a better acquaintance with the conditions by examining other photographs in the report.

VEHICLE DESCRIPTION

At this point a few remarks are in order concerning the vehicles used in this project. At the outset, as described in the Plan of Test, it was intended to conduct trials with four tracked vehicles, the Nodwell RN110, the Nodwell RN35, the M113, and the Canadair CL70 Rat, all supplied by AEEE. Ultimately, availability of vehicles and instrumentation dictated the use of the RN110 and the M113 as the test vehicles. The RN35 had been instrumented but was called away by the manufacturer from the test area during the trials period, and the CL70 Rat was not tested for reasons explained in the Plan of Test.

Both the RN110 and the M113 have been used and described in previous projects. A brief description of these vehicles is as follows:

(a) The M113 is a tracked armored amphibious personnel carrier, is diesel powered, and has automatic transmission, independent torsion arm suspension with dampers on the front and rear road wheels, and live tracks (controlled flexibility) with rubber pads for road travel.

(b) The RN110 is a tracked, non-amphibious personnel and cargo carrier with a gasoline V-8 motor, 4-speed manual transmission, independent spring suspension with no dampers, and continuous rubber belt tracks with stamped steel grousers.

Vehicle design characteristics, which are considered to be pertinent to the conduct of the project, are given for each vehicle in Appendix III, where a photograph of each vehicle also appears.

As this project is concerned mainly with problems of sinkage, rolling resistance, and tractive effort, the vehicle parameters requiring consideration include vehicle weight, track dimensions primarily, and, secondarily, nominal ground pressure, number of road wheels, and sprocket diameter.

These are now considered separately.

(a) It has been noted in previous trials (3), as a result of pressure cell measurements, that the pressure distribution under a vehicle track is not uniform, but is concentrated in varying degrees under the road wheels. Thus, when a vehicle's ground pressure is calculated by dividing its weight by the track contact area, the resultant does not describe the actual pressure distribution.

However, this value (Nominal ground pressure $= \frac{\textit{vehicle weight}}{\textit{track area}}$) is useful as a *general* guide and is referred to in Appendix II.

(b) It is thought that the number of road wheels may have some effect on the rolling resistance of the vehicle, and therefore the number of road wheels per track have been included in the vehicle parameters recorded.

(c) Knowledge of the sprocket diameters is necessary in order to calculate the force exerted on the track by the sprocket.

Other vehicle parameters, such as fuel capacity, have no bearing on the vehicle performance, as measured in these trials, and are not included in the vehicle description.

MEASUREMENT TECHNIQUES AND OBSERVATIONS – TERRAIN

Method

As outlined in the Plan of Test (Appendix I), a number of measurements of terrain characteristics in each of the test areas were undertaken. It was intended that these measurements would provide information that would describe the terrain used in the tests and could possibly be related to vehicle performance to give quantitative insight into the relations between vehicle and terrain characteristics affecting vehicle mobility. All the measurements outlined below are presented in Appendix II – Terrain Description.

Muskeg Cover Type was observed during the test site selection phase according to the Radforth classification system (6). As has already been stated, EI and FI cover types were selected, as they predominate in those areas where low bearing capacity is the main obstacle to vehicle mobility.

Peat Type, Mat Depth, and Composition. This was investigated by obtaining peat samples with a Hvorslev piston sampler having a cylinder approximately 6 in. long and 2 in. in diameter. One sample consisted of three 6-in. cores taken at 0 to 6 in., 6 to 12 in. and 12 to 18 in., respectively. Each core was individually wrapped in a plastic bag, tied at the top and labeled as to depth and top and bottom. Eight samples were taken in each area at random to give a fair approximation of the area. Two of the eight samples were analyzed in the following manner.

The samples were cut open and the individual cores dissected to sort out all fibers. As the sampler could reach a maximum depth of 18 in., mat depth could be determined accurately only if it was less than 18 inches. In most cases it was necessary to estimate the boundary between fibrous material and non-fibrous peat, usually of the amorphous granular type.

Fibers size ranges were studied by using the micrometer to place the fibers in one of the following size ranges:

1/16 to 1/8 in.
1/8 to 3/16 in.
3/16 to 1/4 in.
> 1/4 in.

While it may be considered that fiber length is an important factor controlling peat strength, fiber lengths were not measured because the fibers are chopped up during the sampling process and their original length cannot be determined.

Peat Depth

The depths of peat deposits in the test areas were determined to assure adequate peat depths to allow vehicles to sink during traffic without touching the mineral sub-layer. This was done by probing with rods every 10 ft. along a straight line running across and perpendicular to the test lanes. Depths to the mineral sub-layer were recorded and have been plotted as depth profiles for each area in Appendix II – Terrain Description.

Peat Density

The hypothesis exists that peat density is related to rolling resistance and bearing capacity. Peat densities were therefore measured at several of the test sites. Two techniques were used to accomplish this (7). The first consisted of placing vertically a 2-in. diameter access tube into the ground. A nuclear gamma radiation source and detector were inserted in one tube to known depths, and the source was allowed to radiate into the peat surrounding the access tube. The amount of radiation reflected back to the detector is proportional to the peat density and was measured in counts per minute by a scaler

attached to the detector. Measurements were taken approximately every 20 in. down the access tube and recorded. This is referred to as the single pipe method, and the results have been plotted in grams per cubic centimeter in the "Density" sections of the Terrain Description pages in Appendix II.

The second method uses the same nuclear device, but the source is lowered down one access tube and the detector is lowered to the same depth in a second access tube placed 50 centimeters away. The double pipe system has not been calibrated, so the density scale on the graphs in Appendix II refers only to the single pipe curves.

Peat Moisture Content

Variation in water content among the test areas was evident by visual observation, the indicator being the amounts of free water present on the ground surface or appearing in ruts during vehicle traffic. An attempt will be made in the discussion that follows to relate these moisture conditions to vehicle performance.

Rolling Resistance

The resistance to moving vehicle by soft muskeg is the most significant factor affecting vehicle mobility. By means of data acquired from these vehicle tests, calculations were carried out to determine the resistance to rolling offered to each vehicle by the terrain in each test site, as a function of the number of passes completed by the test vehicle. These data have been plotted in the rolling resistance section of each Terrain Description sheet in Appendix II. Details of the calculations are included in the observations and discussion of this section. However, in general, it can be said that the output force from the vehicle sprocket is absorbed in four ways: the internal rolling resistance of the running gear, the resistance to rolling provided by the terrain, the loss through track slip, and drawbar pull. If it is known that the vehicle is operating with no slip, then the resistance to rolling provided by the terrain will be given by the sprocket output minus the drawbar pull minus the internal rolling resistance.

Symbolically, if

$F_{SPR.}$ = sprocket output force
R_{INT} = internal rolling resistance
R_{EXT} = external rolling resistance
R_{DBP} = drawbar pull

then $F_{SPR.} = R_{INT} + (R_{TERRAIN} + R_{SLIP})^{*} + R_{DBP}$

$F_{SPR.}$ is determined by dividing the total sprocket output torque by the sprocket radius, and is the force available at the sprocket for doing work.

$R_{INT} = F_{SPR.}$ when $R_{EXT} = R_{DBP} = 0$
and is determined by measuring $F_{SPR.}$ on hard ground ($R_{TERRAIN} = 0$) (no bow wave) with zero slip and zero drawbar pull.
R_{DBP} is measured directly.

Therefore, if $R_{SLIP} = 0$ (i.e. no slip during vehicle operation)

$$R_{EXT} = F_{SPR.} - (R_{INT} + R_{DBP})$$

This figure was used in the calculations to determine the terrain rolling resistance curves shown in Appendix II.

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* *R_{EXT} = resistance to rolling provided by terrain (bow wave) + soil vehicle interaction (slip).*

Other Data

In addition to the data required by the project objectives and Plan of Test, some surface roughness and cone penetrometer measurements were taken. It was felt that these measurements would aid in the description of the terrain in familiar terms, and might also provide a link between this project and earlier projects.

Cone Penetrometer

This is an instrument with which many people are familiar and needs little description. Briefly, it consists of a ½-in. diameter shaft with a conical tip at one end (5/8-in. diameter base) and a load ring and dial gauge at the other. Forcing the conical tip into the ground produces a deflection of the load ring and a reading on the dial gauge proportional to the opposition force encountered by the conical tip as it moves deeper into the ground (8).

Cone penetrometer readings were obtained at ten randomly selected undisturbed locations in each test area. These readings were averaged to give the cone penetrometer values presented in Appendix II.

Roughness

Surface roughness values were determined from measurements taken at random in each of the test areas. The distance of the ground surface from a horizontal reference datum was obtained at 4-in. intervals along the datum.

If R = arithmetic mean roughness

n = the number of measurements taken along a single datum line

Yi = an individual height measurement

$\overline{Y}$ = the mean of the n height measurements

then

$$R = \frac{1}{n} \sum_{i=1}^{n} \left| \overline{Y} - Yi \right|$$

In other words, R is the mean absolute value of the deviations of the height measurements from their mean value.

This information is derived from work presented in reference (9). The roughness values included in Appendix II were derived by this method.

Observations

In general, the terrain measurements form the contents of Appendix II – Terrain Description. This is certainly true where cover type, moisture content, roughness, and cone index values are concerned.

The results of the peat sample analysis, however, require some additional tabulation.

Peat Type, Mat Depth, and Composition

Initially it was hoped to place the fibers in a 0 to 1/16 in. range, but this proved very impractical because of the large number of fibers in this range, and because of the very small size of these fibers making it almost impossible to sort all of them.

The results of the fiber counts appear in Table II.

Peat Density

It was possible to obtain peat density measurements in the following areas: Thousand Acre Bog EI, Area 10A, Woods, Thousand Acre Bog FI, and Area 7. No single pipe density data are available for the Woods Area, and no density data are available for Area 66-1.

Rolling Resistance

Where data for resistance of the terrain to vehicle rolling have been collected, they have been displayed in graphs in Appendix II. For reasons to be given in the observations on vehicle performance, vehicle tests were not conducted in Thousand Acre Bog FI and Area 66-1. Only the RN110 was tested in the Thousand Acre Bog EI, and this was only a brief and not very successful test. No data were obtained with zero slip here, so that resistance to vehicle rolling calculations could not be performed.

TABLE II

Area	Depth	Number of Fibers in Each Size Range									Mat Depth in Inches
		0 in.-1/16 in.	1/16 in.-1/8 in.		1/8 in.-3/16 in.		3/16 in.-1/4 in.		> 1/4 in.		
			Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	
Thousand Acre Bog EI	0-6 in.	Too many fibers to count	9	10	2	2	1	1	0	0	
	6-12		15	15	9	3	4	6	1	0	> 18
	12-18		7	1	1	0	1	1	0	1	
10A EI	0-6		8	11	5	6	1	4	7	0	
	6-12		1	1	0	0	1	0	1	0	9.0
	12-18		0	3	0	0	0	0	0	0	
Woods EI	0-6		18	4	6	6	3	5	2	2	
	6-12		0	0	0	0	0	1	0	1	12
	12-18		2	1	0	0	0	2	1	2	
Thousand Acre Bog FI	0-6		33	14	3	6	0	0	0	0	> 18
	6-12		17	8	3	5	0	4	0	0	
	12-18		12	9	5	2	0	0	0	1	
66-1 FI	0-6		11	5	2	0	0	0	1	0	
	6-12		4	4	0	0	0	1	0	0	8.5
	12-18		6	4	0	0	0	0	0	0	
7 FI	0-6		24	5	4	0	2	2	0	0	
	6-12		1	0	1	0	0	0	0	0	3.0
	12-18		1	0	0	0	0	0	0	0	

MEASUREMENT TECHNIQUES AND OBSERVATIONS – VEHICLES

Objectives

It will be recalled from the Plan of Test that the objectives for this section of the work were:

(a) To obtain at each test site for each vehicle simultaneous measurements of drawbar pull, output torque at sprocket, vehicle speed, peripheral speed of drive sprockets, pressure cell output (if possible), pitch angle and sinkage. OATRU measured sinkage.

(b) To obtain measurements on the 1st, 5th, 9th, 19th and 39th passes if possible and convenient.

(c) For vehicles not instrumented to give output torque measurements, to obtain all other measurements where possible.

Method

Tests were conducted in the Thousand Acre Bog EI, Area 7, Area 10A, and Woods area as described in Appendix II, and on hard ground (cinders), with the Nodwell RN110 and the M113.

In each test site, OATRU staff marked out a test lane 100 ft. by approximately 15 ft. with four stakes for each vehicle test. Three additional stakes on one side of the lane indicated the 25 ft., 50 ft., and 75 ft. points in the lane.

AEEE positioned the test vehicle at the entrance to the lane and facing it. The Water Buffalo acting as a load vehicle was attached to the test vehicle by a 100 ft. cable to avoid having the load vehicle travel in the test lane and distorting data taken after the first pass.

All measurements on vehicle performance except sinkage were obtained by AEEE.

The test vehicle was operated in the test lane in low gear. An attempt was made to obtain measurements with a variety or range of readings of output torque, with corresponding drawbar loads to give low, medium, and high slip of the test vehicle. Sinkage measurements were taken at the points 25, 50 and 75 ft. stations in the test lane.

The test vehicle traveled back and forth in the test lane until it completed a total of four passes. The measurement procedure performed on the 1st pass was then repeated on the 5th pass. Measurements were again repeated on the 9th, 19th and 39th passes. The test was terminated if immobilization occurred or appeared imminent.

Instrumentation

In order to obtain the measurements noted above, a considerable amount of instrumentation was required and was supplied by AEEE. Most of the quantities (drawbar pull, sprocket output torque, vehicle speed, peripheral speed of drive sprockets, and pitch angle) were fed simultaneously to a 7-channel oscillograph with a chart speed of about 10 in./sec. The oscillograph and power supply were mounted in the M113. When a vehicle other than the M113 was under test, the M113 traveled beside the test vehicle, and was connected to it by a multiconductor cable suspended between the test vehicle and the M113, which was in a parallel test lane.

For drawbar pull measurement, a strain gauge type load cell (Fig. 1) was inserted in the tow cable joining the test vehicle and the load vehicle.

Torque of both drive sprockets on the test vehicle was measured by boring a hole axially in the outboard ends of the half shafts (Fig. 2), and attaching strain gauges to the walls of the holes. Slip rings

(Fig. 3) were mounted on shaft extensions (Fig. 4, Fig. 5) to connect the strain gauges to the recorder. This provided a continuous record of the torque on each drive sprocket of the test vehicle.

The test vehicle speed was measured by towing a "fifth wheel" (Fig. 1) behind the test vehicle. The fifth wheel powered a small D.C. generator whose calibrated output voltage was proportional to the vehicle speed and was continuously recorded by the oscillograph.

The vehicle track speeds were measured by mounting D.C. generators on brackets near the drive sprockets (Fig. 6) and driving them with the half shaft extensions, mentioned earlier, through flexible couplings. Their calibrated output voltages were recorded on the oscillograph, and these measurements were later combined with the vehicle speed measurements in the calculation of track slip.

Pitch or trim angle of the test vehicle was determined by mounting a damped pendulum on the vehicle. The pendulum was attached to a rotary potentiometer (Fig. 7). Ideally, if the vehicle tilted, the pendulum would continue to hang vertically, resulting in movement of the contact wiper in the potentiometer. Thus, a voltage proportional to the tilt angle of the vehicle would be produced by the potentiometer and could be continuously recorded on the oscillograph.

Sinkage of the test vehicle was not measured continuously, but discrete measurements were obtained at the 25-ft., 50-ft., and 75-ft. stations in the test lane on each pass. This was accomplished by attaching a scale marked in inches to the side of the test vehicle (Fig. 8), sighting on the scale through a surveyor's level, and recording the scale reading as the scale passed the marker stake at each of the three stations in the test lane. The zero sinkage reference value was obtained by sighting on a portable scale (Fig. 9) at each of the three stations before the vehicle entered the test lane.

An attempt was also made to obtain measurements of pressure distribution in the peat under the test vehicle tracks by inserting a pressure cell in the peat. Details of the measurement technique are given in reference (3).

Observations

Due to several difficulties that arose in the course of the field program, it was not possible to utilize all the test areas that had been selected. In addition to the measurements already described, notes were taken concerning the general performance of the vehicles and instrumentation and difficulties that arose during the tests.

Tests were conducted in Thousand Acre Bog EI, Area 10A, Woods Area, and Area 7. A narrative of events is given below in chronological order.

RN110

3 July-5 July:

Before any testing could be undertaken it was necessary to have available not only the test vehicles and instrument vehicle, but also complete instrumentation. Slip rings to be used in the torque measurements did not arrive in Parry Sound until approximately 3 July, and two or three days were needed to complete their installation on the M113, as the end seals required modification. Some difficulty was also encountered in preparing the oscillograph paper processor for use.

6 July – Thousand Acre Bog Wet EI:

The first test here was attempted 6 July in the afternoon. It was not a great success, mostly owing to the very high water content of the area. It was necessary to operate three vehicles, the RN110,

the M113, and the Water Buffalo simultaneously, and if one became immobilized, the other two were compelled to stop. This happened two or three times, even before one pass had been completed.

Vegetation was torn up by the tracks on the RN110, accumulated quickly around the fifth wheel, and prevented it from turning. Tests were halted at this point and were continued the next day.

The fifth wheel was then attached to a bracket, which extended out to the side of the RN110 (Fig. 10). This prevented accumulation of vegetation on the fifth wheel.

However, the high water content resulted in extreme sinkage (Figs. 11, 12) greatly reducing drawbar pull available from the RN110, and submerging the slip rings and DC generators mounted on the drive sprockets. Wiring was torn apart (Fig. 13) by peat trapped between the vehicle tracks and hull, and water entered the slip rings and DC generators, destroying their output signals.

As a result of these experiences, it was decided to discontinue tests in the Thousand Acre Bog, attempt tests in other drier areas, and if time remained in the test period, return to the Thousand Acre Bog afterwards to complete the tests.

While driving the vehicles cross country from the Thousand Acre Bog to the road, a spindle on one of the RN110 road wheels broke as the vehicle was attempting a turn while crossing a sharp rock ridge. The break (Fig. 15) appeared to be a fatigue failure.

11 July-15 July:

An interval of M113 tests followed at this point but, for the sake of continuity, observations on the remaining RN110 tests are noted here.

17 July – Hard Ground:

Measurements had been taken on hard ground at the AEEE camp with the RN110 on 17 July (Fig. 16). The FWD truck loaded with sandbags was used as the drawbar load vehicle. The RN110 did not carry a load for this test, and this was taken into account in the calculations used to obtain the curves in Appendix III.

17 July-20 July – Woods Area Dry EI:

On 17 July, the M113 and RN110 were driven along the shoulder of Highway 69 from the AEEE camp near Nobel towards the Woods Area (see map, Appendix II). About three miles of this journey remained when one of the shaft extensions on the RN110 broke (Fig. 17), tearing the leads from the slip rings.

The next day a new shaft extension was prepared and installed (Fig. 18), and the journey to the Woods Area was completed.

The RN110 test in the Woods Area was, in the end, completely successful. On the 9th pass, a very high drawbar pull snapped the tow cable, and a heavier cable had to be substituted. Thirty-nine passes were completed without difficulty. Sinkages were much lower than had been experienced in the Thousand Acre Bog, and the RN110 had no difficulty in exerting very high drawbar pulls and completing its tests. Moisture regime was quite low in this area (Fig. 19).

20 July – Area 10A Moist EI:

The RN110 test in this area was also successful, and 39 passes were completed. Fig. 20 shows the relatively low water regime that existed in this area.

21 July – Area 7 Dry FI:

Thirty-nine passes were completed here also with no difficulty. The date for ending the field program had been set at 22 July, so that no further tests were conducted after this date. As a result, Area 66-1 was not used for testing, and there was no opportunity to return to the Thousand Acre Bog.

M113

11 July-12 July – Hard Ground:

All of 11 July and part of 12 July were required to set up and adjust instrumentation on the M113.

The hard ground test of the M113 was successfully completed on 12 July, using the FWD as a load vehicle.

13 July-14 July – Area 7 Dry FI:

Several events of interest occurred during this test. On the 1st pass, the 3/4-in. tow cable broke and had to be repaired. It broke again twice during this test and repairing it delayed the test somewhat.

Sinkage of the vehicle progressed rapidly with traffic. The vehicle belly was dragging on the ground on the 5th pass (Fig. 21), and immobilization occurred on the 8th pass (Fig. 22) about 10 ft. inside the entrance to the test lane. After being recovered, the M113 continued traffic in the remainder of the lane until it again became immobilized at the 50 ft. station during the 19th pass.

14 July – Area 10A Moist EI:

No mechanical or electrical difficulties arose during this test. Ruts developed in the mat as traffic progressed and, by the 9th pass, the mat was being cut at one point in the test lane (Fig. 23). Traffic continued until the vehicle became immobilized at that point on the 29th pass. Mat deterioration was most severe during passes for which the vehicle was exerting a high drawbar pull.

15 July – Woods Area Dry EI:

No trouble was encountered either in traveling along Highway 69 to the Woods Area or in completing 39 passes in the test lane in that area. However, it appeared that immobilization would probably occur on the 40th pass.

At this point in the program a decision concerning plans for the remainder of the test period was made. Five days had been required to complete tests on the M113 on hard ground, and in 3 muskeg areas. One week remained in the test period. To continue tests with the M113 would mean venturing into areas with fairly high water levels and risking water damage to slip rings and DC generators. These would have to be repaired before tests could be resumed and, by that time, there might have been two days at most remaining in the test period. Therefore it was decided that the RN110 would undergo the tests on hard ground and in the 3 drier muskeg areas, and that this would probably occupy most of the remaining week from 16 July to 22 July. This turned out to be the case as has already been described, so that an opportunity to conduct further tests in Area 66-1 and the Thousand Acre Bog did not arise.

The only remaining observation is that several interesting features of vehicle drive train behavior became evident on the oscillograph records. As these records require interpretation, consideration of them has been included in the discussion section that follows.

DISCUSSION OF TEST RESULTS

Terrain Selection. In retrospect, the test areas selected were certainly the best available for the purpose. They provided sufficient space for testing, the peat depths were all adequate to allow for vehicles

sinking without penetrating to the mineral sub-layer, and a satisfactory range of moisture contents was available. Ideally, however, it would have been better to have had a larger difference in moisture contents between Area 10A and the Woods area.

Test Vehicles. The vehicles finally used in this project, the Nodwell RN110 and the M113, were very well suited to the project. Their test weights and hard internal rolling resistances were approximately the same, and their output torque ranges were similar. This implies that differences in performance on soft muskeg can probably be attributed mostly to track dimensions and design, as far as these two vehicles are concerned.

TERRAIN MEASUREMENTS

Muskeg Cover Type. It was generally evident that the vegetal cover within the test lanes was fairly homogeneous. However, there were local variations in cover, which were not very obvious from the ground and which corresponded to slightly varying structural properties in the peat below the surface. This accounts for the occasional immobilization of the M113 at specific locations within test lanes. If the surface cover and sub-surface properties were completely homogeneous, it could be expected that the degree of deterioration of the mat under traffic would be uniform along the entire length of the test lane. This, in fact, rarely happens, and the relative inhomogeneity of the surface cover in the 6 test areas is quite evident in the air photographs in Appendix I and supports the case.

Peat Type, Mat Depth, and Composition. Generally speaking, EI cover type areas seemed to show a greater number of fibers especially in the higher size ranges (See Table II). FI cover type areas appeared to have a high fiber content in the lowest size range, but fewer fibers in the higher size ranges. This might be expected because of the woody nature of EI areas as compared to the non-woody vegetation in FI areas. Woody types (both stems and roots) will be in greater quantity in larger sizes and these will resist decay longer than the smaller non-woody fibers. However, the FI area in Thousand Acre Bog shows a high number of fibers of medium size especially in the 6-12 and 12-18-in. depths, where one might expect fewer fibers. This may indicate the presence of EI vegetation in this area at some time in the past. Both the EI and FI from the Thousand Acre Bog show much greater numbers of fibers in the lower depths (6-12 and 12-18 in.) than appears in any of the other bogs.

Some areas show horizontal layering corresponding to early deposition and partial decay. These layers would be better shown up by a smaller interval than 6 in. being studied. Woods area, for instance, consistently shows very few fibers of any size in the 6-12-in. layer, but with more fibers in the 12-18-in. layer. Therefore fiber size and number would seem to be very indicative of previous surface vegetation.

Several points concerning the sample analysis are perhaps worth mentioning:

1. Fibers are not the same diameter throughout their length. The largest diameter of the piece was therefore used in obtaining the data in Table I and II.

2. Some fibers were partially decayed and flattened, necessitating a certain amount of estimation of their diameter (especially non-woody types).

3. Fibers may be only one or parts of one that have broken off in sampling or counting, giving an incorrect number. It has been assumed that this factor should be reasonably constant in all cases so that the numbers should be considered in relative proportions.

4. The counting method of simply crumbling the peat in one's hand was not efficient enough to guarantee collection of every possible piece – especially pieces of very soft constitution or very short length.

5. Sampling always involves some compression of the mat and peat, so that sample length and actual depth will not correspond exactly. For the same reason, there may be some slight overlap in sampling, especially in very wet areas where compression is higher.

6. Only two sets of samples were used for this preliminary test, which serves as an approximate description of each area.

This fact combined with the variations in the data make it questionable that a precise quantitative relation could be established between the fiber count and mat depth, on one hand, and the bearing capacity and resistance to rolling provided by the terrain, on the other.

The above comments make it clear that this method of peat analysis is not very practical for helping to predict peat structural properties, as final results are not very meaningful and require a considerable amount of time to obtain.

This lends weight to the suggestion that a more convenient and faster technique of measuring a physical property or properties of the peat, such as moisture content, may provide the most convenient means of relating peat types to their bearing capacity and rolling resistance. A descriptive system as has been attempted here might be useful if done on a statistical basis, but this would be such a huge task that it would be worth-while investigating alternative methods before attempting it.

Peat Depth

It is sufficient to say here that all areas in which tests were conducted contained peat at least 2 ft. deep, as can be seen from the depth profiles in Appendix II. This would provide sufficient depth to allow for vehicle sinkage without touching the mineral sub-layer.

Peat Density

Reference is made here to the peat density curves that appear in Appendix II. It will be recalled that two methods of density measurement were used; single pipe and double pipe. The gm/cm^3 scale applies only to the single pipe curves.

It appears from these curves that the peat density in the test areas range from about 0.75 gm/cm^3 to 1.25 gm/cm^3. The higher densities in this range occur in those areas with relatively low moisture contents. Low moisture content would allow some decomposition of dead plant material, destroying some of its cellular structure and allowing closer packing of the remaining cell wall material. This reduced void ratio would correspond to a high density of the solid component of the peat water mixture. In the EI areas, density increases as moisture content decreases from one area to the next, but in each EI area density decreases with depth. If the relation between density and moisture content holds within one test area, then the density curves for the Thousand Acre Bog FI suggest very high moisture content 4 to 5 ft. below the surface, probably accompanied by fairly low peat content.

These peat density measurements show some promise in that they describe the terrain in an easily comprehensible manner, and provide a quantitative result that may be related to bearing capacity and rolling resistance. This possibility will be explored later in the discussion.

Rolling Resistance

Rolling resistance curves are presented in Appendix II for each area in which tests were performed. Rolling resistance was calculated as described earlier (Measurement Techniques and Observations — Terrain).

When the data were first examined, a plot was made of external rolling resistance/track width vs. number of passes. It was hoped that this would show an expression of external rolling resistance that would be independent of type of track. However, it resulted in a distinct separate curve for each vehicle,

with the M113 having a higher rolling resistance per unit track width than the RN110. When the sinkages of the two vehicles in each test was reviewed, it appeared that M113 sinkages were all greater than those of the RN110. This factor was taken into account by plotting rolling resistance/track width × sinkage vs. number of passes. The result was that the points all fell fairly close to a single curve as can be seen in Appendix II.

With the data available, it has been possible to present external rolling resistance curves for Area 10A, Woods Area and Area 7. The shapes of the curves are rougly the same in all 3 cases and generally they indicate the following points:

1. External rolling resistance per unit submerged frontal track area normal to the ground surface is dependent on the terrain. (Data from two vehicles follow one curve.)

2. External rolling resistance is highest during the first few passes, reaches a minimum between 10 and 20 passes, and gradually begins to increase again.

3. External rolling resistance does not *appear* to vary directly with moisture content but, with the evidence of only 3 curves, it would be dangerous to state this conclusively, especially since the 3 test areas considered represent a very narrow range of moisture contents.

Some scattering of the points about the curves is evident and could be due in part to the fact that:

1. The sinkages used in the calculations were the average of 3 visual sinkage measurements taken along the test lane on each pass of the vehicle. If it had been possible to obtain continuous sinkage measurements, it is likely that more precise sinkage values related to specific torque outputs could have been used in the calculations.

2. When the method for calculating resistance to rolling provided by the terrain was explained earlier, it was pointed out that the resistance to rolling provided by the terrain was the difference between the sprocket output and the combined internal rolling resistance and drawbar pull when the slip was zero. The available oscillograph charts did not in a few cases provide data with zero slip. When this occurred, calculations were done with data procured with less than 10 per cent slip.

Cone Index

In general, the cone index values exhibit an increase with decreasing moisture content, (as evaluated by visual observation), especially in the 0-6-in. layer. The range of cone index covered by the EI areas is roughly the same as that covered by the FI areas. This suggests that given cover types cannot be uniquely related to specific cone index ranges. Limited experience of the trials suggests that moisture content is the dominant factor in controlling cone index values.

Roughness

The roughness values that appear in Appendix II are all less than 3 in. indicating an average vertical peak to valley distance of less than 6 in. in all areas utilized. This value would grow even smaller under the weight of a vehicle, so that it is likely that little or no contribution to rolling resistance exists from mounding of the ground surface profile.

Vehicle Measurements

The discussion of this section is divided into two main parts: Instrumentation, and Analysis of Test Results.

Instrumentation

Drawbar Pull Measurement

The load cell (provided by AEEE) used to obtain drawbar pull measurements performed very satisfactorily in that it was both rugged and sensitive. It gave readings from 0 to 24,000 lbs., withstood heavy shock loads from the tow cable, and total immersion in water. Its output, as seen in the lower trace of Fig. 24 (one horizontal division corresponds to about 0.1 sec.) responded easily to load changes occurring in less than 0.01 sec. Fig. 24 shows the effect of the tow cable snapping under a load of 20,000 lbs. Apparently the break occurred in two stages about 0.2 sec. apart.

Torque Measurement

Measuring output torque by inserting strain gauges in the drive axles is recommended. The performance of the set-up used in this project, however, depended on the immediate environment of the drive sprocket. If the slip rings were kept dry and free from accumulations of peat, no difficulty was encountered. If they were submerged in water, as was necessary in some cases, the torque signal was lost and the slip rings required complete dismantling. This occurred even though an attempt had been made to waterproof the slip rings with tape and silicone rubber.

Fig. 25 shows oscillograph traces of the rapid oscillation of the M113 output torques (oscillating traces in bottom half of photo). The oscillation in these traces caused difficulty in taking precise torque measurements from the chart paper during the data analysis. The procedure resorted to was to draw an estimated mean line through the trace and use this mean line as the torque reading.

Vehicle Speed Measurement

The fifth wheel arrangement was generally satisfactory although the wheel itself sometimes rode over a clump of vegetation that the vehicle did not "notice". When this happened, the wheel momentarily speeded up so that it gave a reading higher than the true speed of the vehicle.

Peripheral Sprocket Speed Measurement

This apparatus also performed well in general, but would benefit from additional waterproofing for the same reasons already given for the torque measurement.

Pitch Angle Measurement

The results obtained from the pitch angle meter have been plotted against drawbar pull in Appendix III. The wide scattering of the points on these curves is partially due to the underdamped oscillation (Fig. 26) of the pendulum, which resulted in reading errors of as much as $\pm 3°$. In these trials, the vehicle pitch angle has not appeared to be of major significance. However, if pitch angle measurement is contemplated for future projects, better damping and faster response (about ten times as fast) of the pendulum would be highly desirable.

Sinkage

The method of sinkage measurement used is definitely superior to measuring vehicle rut depth after the vehicle has passed by. By measuring the actual vertical position of the vehicle, the effect of elastic rebound of the mat surface after the vehicle has passed is avoided. However, since measurements

were recorded separately from the oscillograph records, it was impossible to relate any given sinkage measurement to a specific set of measurements on the oscillograph chart. This detracts from the precision of the results obtained in the data analysis.

Analysis of Test Results

The results of the data analyses have been presented in graph form in Appendix III. The meaning of each graph becomes evident upon studying the labels on the axes and the legends provided.

Ratio of Drawbar Pull to Vehicle Weight vs. Slip (single pass)

$$\left(\text{Slip} = \frac{\text{peripheral sprocket speed-vehicle speed}}{\text{peripheral sprocket speed}} \times 100\right)$$

First of all, most of the curves in these graphs for both the RN110 and the M113 have several features in common. If any curve, say the solid line representing the hard ground test, is selected, it will be seen that it really consists of two curves, an upper and a lower. The upper curve of a pair represents drawbar pull weight ratio vs. slip for increasing drawbar load, and the lower curve represents the same relation for decreasing drawbar load.

The hard ground curve for the RN110 was obtained with the vehicle carrying no payload, which probably enabled it to attain the maximum slip of 100 per cent as shown. In the muskeg test sites full payload was carried and, in the drier areas, insufficient torque was available from the engine to produce 100 per cent slip. This indicates that the RN110 track design is such that in several common terrain conditions all available engine torque is utilized. For the RN110, the maximum drawbar pull was the same for all test areas except Thousand Acre Bog EI, where sinkage and water content were relatively high. In this area, a large proportion of the sprocket output was obviously devoted to slip and rolling resistance. In Area 7 FI, maximum drawbar pull was the same value as in the drier EI areas, but was attained at a lower slip.

From the M113 curves in comparison to those of the RN110, it appears that, on muskeg, slip of the M113 tracks increases more rapidly with increasing drawbar load than does slip of the RN110 tracks. While the drawbar pull from the M113 does not reach a maximum limit with increasing slip as does the RN110, its maximum drawbar pull, except on dry EI is lower than that of the RN110. M113 drawbar pull on dry FI is much lower than RN110 drawbar pull in the same area.

Drawbar pull vehicle weight ratio vs. slip has also been plotted for each vehicle with data taken after multipass traffic (5, 9, 19, 29 and 39 passes) in Appendix III.

With reference to the RN110 curves, it appears that maximum drawbar pull can be achieved between 10 and 20 passes on moist to dry EI and at about 20 passes on dry FI. After 1 and 5 passes little difference in maximum pull exists between one area and another. However, as traffic continues, it appears that there is a slight difference in maximum drawbar pull between the two EI areas, greater pull being achieved in the drier Woods area.

There is implied here a definite relation between moisture content and drawbar pull within a given muskeg cover type. Reliable measurements of percentage moisture content would facilitate exploration of this relation.

The M113 multipass drawbar pull curves generally support this suggestion. Thirty-nine passes were completed in only one test area (Woods EI) and maximum pull was achieved on the 19th pass. From Appendix II, rolling resistance in this area was near its minimum at 19 passes. This information indicates again that the mat strength is increased by 10 to 20 passes of a vehicle in moist to dry EI. The maximum pulls of the M113 were lower in all cases than those of the RN110 and, in general, were attained with greater slip. This further indicates that the track design of the RN110 converts more of its output force to tractive effort and less to slip losses than does the M113.

Efficiency of Tractive Effort

Appendix III also contains what might be called tractive effort efficiency curves for which $\frac{\text{Drawbar Pull}}{\text{Sprocket Output}} \times (1 - \text{slip}) \times 100$ has been plotted against ratio of drawbar pull to vehicle weight for first pass data from each test site. This can be considered as the ratio of useful work output (Drawbar pull) to work supplied by the automotive system to the track through the sprocket, and could be called tractive effort efficiency. This ratio or efficiency is plotted as a function of ratio of drawbar pull to vehicle test weight.

It may be seen from the curves that for both the RN110 and the M113 peak efficiencies are reached corresponding to different drawbar pull ratios in the various terrains. The RN110 tracks exhibit uniformity in their "tractive effort efficiency", but near-peak efficiency occurs over a considerable range of drawbar pulls. The M113 track appears to be more efficient on hard ground, but its peak efficiency on muskeg appears to be sensitive to the gross terrain conditions upon which it was tested. Also it should be noted that peak efficiencies are obtained only over a limited range of drawbar pull ratios.

Pitch Angle

Some remarks have already been offered concerning the validity of the pitch angle measurements. Therefore the curves showing pitch angle plotted against drawbar pull are rough approximations at best. However, two features are evident in these curves for both the RN110 and M113. First, the gentle slope of the curves suggests that pitch angle is almost independent of true drawbar pull in pounds. Secondly, it appears that a separate curve exists for each test area, which strongly suggests that pitch angle is very dependent on terrain conditions that probably are in turn dependent on muskeg type and moisture.

Sinkage

Appendix III contains curves showing vehicle sinkage plotted against number of passes. For the RN110, most of the sinkage occurs within the first 10 to 20 passes, after which the sinkage rate decreases to almost zero. For the M113, sinkage occurs in larger amounts on the first pass and at a greater rate thereafter. The M113 curves do not all continue to 40 passes, as the vehicle sometimes became immobilized because of slip under heavy drawbar load before 40 passes had been completed. The curves for both vehicles indicate that sinkage increases with increased ground pressure and moisture content, and also depends on the muskeg cover formula reflecting the peat structure beneath.

Comparison of Results with Previous Trials

Previous mobility trials have been conducted on muskeg in the Parry Sound region for several years. The objectives of these trials have been the observation of a wide variety of vehicle types operating in muskeg having a complete range of vegetal cover and the study of mobility principles. An attempt was made to use cone index, subsidence, and multipass traffic together with qualitative performance observations to assess:

(a) the obstacles offered to vehicle mobility by various terrain conditions,

(b) the effectiveness with which various vehicle concepts overcame the obstacles imposed by the terrain mentioned in (a) above.

The net result of these tests was that a wide variety of terrain conditions and problems exists and that no one vehicle concept can deal effectively with all the conditions. On the other hand, some vehicle concepts are better than others at overcoming certain specific obstacles.

Taking past experience into account, it was necessary to establish a program of quantitative measurement of terrain and vehicle performance relations narrower in scope but in greater depth of detail.

This project, an examination of the mobility of tracked vehicles in soft muskeg, is a beginning. Whereas in the past a large number of vehicles has been subjected to a few measurements and to a great deal of qualitative observation, this project considered a single terrain condition, soft muskeg and, for ease of comparison, two vehicles of similar configuration were used (see Appendix III), and measurements were made of the factors thought to control performance of these vehicles.

From the results obtained it appears that the objectives have been at least partially achieved. It is difficult to compare the results of this project directly with those of previous projects, which were qualitative as to the comparison of general performance, but in which the vehicles were not as fully instrumented as the vehicles in these trials.

It is true that formerly drawbar pull ratios vs. slip data had been obtained but only in one terrain condition and for one pass. This yielded some information, but it was difficult to relate. With the measurements taken this year, definitive relations have been established that were not known before.

These are outlined in the following conclusions.

CONCLUSIONS AND RECOMMENDATIONS

In the light of the foregoing discussion, it is possible to re-examine the four hypotheses proposed in the foreword.

(a) "Sinkage rate for a standard load is proportional to moisture content of the peat."

From the sinkage rate curves in Appendix III, it would appear that this is possibly the case. For a single vehicle operating in several areas, sinkage rates were all very similar. However, the moisture content range covered by the test areas used was quite narrow except for the Thousand Acre Bog. If all the test areas had been utilized, the validity of this hypothesis could have been better established. As it stands now, it is quite possibly true but requires more evidence to confirm it.

(b) "Sinkage for a standard static load is proportional to diameter and number of woody and non-woody stems."

The results of the peat sample analysis suggest that the counts of fibrous content in a peat sample are insufficiently reliable and repeatable to validly examine this hypothesis.

(c) "Rolling resistance is proportional to sinkage rate/unit load pressure, weight of vehicle, mean ground pressure of vehicle, number of road wheels, track width, and pressure variation amplitude along track length."

It has been shown fairly conclusively that resistance to rolling provided by the terrain is a function of cover type, moisture content, and submerged vehicle track frontal area normal to the ground

surface. Submerged track frontal area is determined by track width and sinkage, and sinkage is controlled by the vehicle weight and ground pressure, and also by muskeg cover type and moisture content.

With the precision of the data available, no effect of the number of road wheels per track could be determined. Also, no pressure cell measurements could be obtained, so that the contribution of track pressure distribution could not be assessed. However, it is suggested that water content, cover type, track width and sinkage are the major factors controlling total rolling resistance of the terrain to a given vehicle.

(d) "There is a relation between drawbar pull, slip, and muskeg type, as described by a quantitative classification system."

The evidence obtained in this project supports this hypothesis, but the hypothesis should be qualified by saying that "the relation exists for a given vehicle but the relation for one vehicle may be different than for another".

As a result of this project it can also be suggested that a suitable muskeg classification system would combine the Radforth vegetation classification system with moisture content measurements in per cent water content per unit volume of peat – water mixture.

The relation would have to be established empirically for each new vehicle track design investigated but, once established, there would then be a means of predicting the drawbar pull performance of that vehicle on any muskeg of EI or FI cover with known water content.

Relation of Design Concept to Vehicle Mobility

With reference to drawbar pull performance, if the track dimensions and designs of the two vehicles are examined, it will be seen that while the track lengths are not very much different, the track width of the RN110 is almost three times that of the M113. The RN110 track is relatively smooth, and the grousers are flattened near the edges of the track. The M113 track has vertical knife-like cleats extending from either side of the central track pads. The higher sinkage rates of the M113 and visual observation of its performance suggest that the narrow tracks, giving a high pressure per unit area, and the aggressive grousers, producing a cutting action, combine to cut the muskeg mat, reducing its shear strength and encouraging high slip with increased drawbar load.

The results shown in the tractive effort efficiency curves in Appendix III and discussed earlier lend weight to this argument. The RN110 tracks worked more efficiently and more consistently on muskeg, than did the M113 tracks.

From the point of view of sinkage, it has been shown that the M113 sinkage was generally greater than that of the RN110. This contributed to dragging the vehicle belly part way through some of the tests, resulting in immobilization. Larger track area on the M113 would reduce sinkage and allow more passes over the same path without immobilization.

Summary of Important Conclusions

1. There is a definite relation between moisture content and drawbar pull performance in which, with increasing moisture content, maximum drawbar pull decreases and slip increases. See drawbar pull curves in Appendix III.

2. Tracks of the RN110 type produce more efficient tractive effort on moist EI and FI muskeg than do those of the M113, because of their greater contact area, which lowers sinkage and rolling resistance, and because of their less aggressive grousers, which minimize shear failure and slip.

Recommendations

1. Any further testing should include measurement of percentage moisture content of muskeg, and the measurements should be compared with, and if possible related to, drawbar pull, sinkage, and rolling resistance.

2. It is recommended that tests scheduled for this project, but not completed, be performed in order to verify and confirm evidence already gathered.

3. The following recommendations are made with reference to improvements in instrumentation and techniques, which might be incorporated in future tests:

   (a) All tests should include a section with zero slip, in order to facilitate accurate rolling resistance calculations.

   (b) Torque and speed measuring equipment should be completely waterproofed to allow submerged operation if necessary.

   (c) Modification of the pitch angle meter to obtain faster response and better damping should be investigated.

   (d) Provision should be made for continuous sinkage measurement to be recorded simultaneously with other vehicle performance characteristics.

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APPENDIX I

PLAN OF TEST

VEHICLE RESEARCH – MUSKEG 1966

PLAN OF TEST

INTRODUCTION

This is a plan of test prepared in accordance with the Defence Research Board Statement of Work for Vehicle Research – Muskeg 1966. Broadly speaking, the aim of the project is to determine the effect of particular vehicle and organic terrain characteristics on the mobility of vehicles. This is to be accomplished by noting specific vehicle and terrain characteristics and performance figures, and attempting to derive quantitative inter-relations between these characteristics. Specifically, the program will involve examination of tracked vehicles operating on muskeg with FI and EI cover, and on a variety of water regimes.

TEST PROGRAM SCHEDULE

The field program will be conducted jointly by the Organic and Associated Terrain Research Unit (OATRU) of McMaster University and by the Army Equipment Engineering Establishment (AEEE). The following schedule will be followed as closely as possible.

Because of delays arising from failure of some test vehicles to arrive at the test area, preparation of test instruments requiring considerable time, and late arrival of some test vehicles, it has been necessary to revise the original plan of test and to include an extension of the test period.

In the revised plan of test, the test vehicles are the RN110, RN35, and M113. The CL70 Rat, while available for use, is not instrumented to give torque output or drive train speed readings. Owing to shortage of time, it has not been included in the revised test schedule, but if time permits at the end of the schedule in the period allotted for completion of tests, drawbar pull and sinkage measurements will be made with the Rat.

This revision is being prepared on 10 July, 1966, as required for the reasons noted above. It will be seen that the first date on the vehicle test schedule is Wednesday, 6 July, 1966. A previous revised vehicle schedule was prepared on 17 June, 1966, when it became apparent that late arrival of vehicles and equipment at the site would necessitate such a revision. This is, therefore, the second schedule revision. It will also be seen that the section from 6 July to 10 July describes only one vehicle (RN110) test in the Thousand Acre Bog before moving to the next test site. This portion of the schedule is complete at time of writing, and the other test vehicles were not tested in this area because of damage to instruments from the high water level in this area. The other test areas have a lower water level and instrument damage is not expected to be so great.

SCHEDULE FOR OATRU – DRB – AEEE FIELD OPERATIONS 1966

Phase I	Preparation and Test Area Selection
8 May	OATRU aerial reconnaissance of possible test areas
24 May	OATRU Staff Depart from McMaster University and travel to Parry Sound Set up camp
25 May to 30 May	OATRU selection of test sites preparation of access routes
1 June to 5 July	AEEE preparation of instruments vehicle maintenance and preparation assistance in terrain data acquisition
	OATRU density, cone penetrometer, roughness depth profile measurements, peat sampling

SCHEDULE FOR OATRU – DRB – AEEE FIELD OPERATIONS 1966

Phase II **Vehicle Testing in the Field**

Date	*Job*	*Location*
Wednesday, 6 July	Test RN110 in EI	Thousand Acre Bog
Thursday, 7 July	Continue RN110 test in EI	Thousand Acre Bog
Friday, 8 July	Move vehicles to area 7 Perform maintenance on vehicles and instrumentation as necessary	
Saturday, 9 July	Continue vehicle and instrument maintenance	
Sunday, 10 July	Instrument maintenance	
Monday, 11 July	Complete vehicle move to area 7 Test RN110 in FI	7
Tuesday, 12 July	Test M113 in FI Test RN35 (if available) in FI Move to area 10A	7
Wednesday, 13 July	Test RN110 in EI Test M113 in EI Test RN35 (if available) in EI	10A
Thursday, 14 July	Move vehicles to Woods Test RN110 in EI Test M113 in EI	Woods
Friday, 15 July	Test RN35 (if available) in EI Move to area 66-1, gravel pit Test RN110 on hard ground Test M113 on hard ground	66-1
Saturday, 16 July	Test RN35 on hard ground	
Monday, 18 July	Test RN110 on FI Test M113 on FI Test RN35 (if available) on FI	
Tuesday, 19 July to Friday, 22 July	Complete tests which have been delayed owing to breakdowns and repairs	

SCHEDULE FOR OATRU – DRB – AEEE FIELD OPERATIONS 1966

Phase III	Report Preparation
16 July to 31 August	Data reduction and analysis of results Preparation of draft report Editing of 16 mm film Preparation of film script

Phase IV	Report Revision
1 September to 30 December	Preparation of Final Report through liaison between OATRU and the Defence Scientific Information Service
30 December	Submission of Final Report to the Chairman, Defence Research Board

Test Area Selection

Field testing will be conducted in confined muskeg areas near Parry Sound, Ontario. The test areas used will have EI and FI cover, will be of low, medium, and high water regime, and will be of sufficient area to accommodate 6 100-ft. test lanes, each with additional space for load vehicles and maneuvering.

An aerial reconnaissance expedition will be made in the Parry Sound region to inspect possible test areas located previously on aerial photographs. Cover type and approximate water regime will be noted and photographs taken. A later flight may be necessary to procure oblique aerial photos of the test sites when these have been selected.

As a result of the reconnaissance flight, possible test areas will be investigated on foot and, if they are found to have the above specifications, access routes will be chosen and prepared as necessary.

Test sites will be selected and marked prior to vehicle testing. In previous vehicle projects, test lanes have all been staked out in advance. This has necessitated procurement of large numbers of marking stakes and expenditure of considerable labor, time, and effort. In an attempt to avoid this expenditure, up to 10 stakes will be used to mark test lanes prior to each test, and will be moved to mark the lane for the next test.

An attempt will be made to keep each site uniform in cover type and water regime when it is selected, so that all vehicles will undergo the same experience when operating on the site.

VEHICLE TESTING AND DATA ACQUISITION

Vehicles to be tested are named in the list below:

Group I	M113		
	RN110	Group II	CL70 Rat
	RN35		

A 100-ft. long test lane will be marked out at each test site for each vehicle. The load vehicle will be attached to the test vehicle by means of a 100-ft. tow cable to prevent the load vehicle from traveling in the test lane. The test vehicle will be operated under load at a pre-determined torque output and performance data will be recorded.

The tests will be repeated for each vehicle on hard gravel to determine the contributions to rolling resistance made by the vehicle running gear.

The terrain and vehicle data to be measured are noted in the table below, together with the means for obtaining each type of data.

Data	Measurement Technique
1. Vehicle track length	Tape
2. Vehicle track width	Tape
3. Vehicle weight	Weigh scale or spec.
4. Number of road wheels	Inspection
5. Muskeg cover type	Inspection
6. Peat type	Inspection, sampling analysis
7. Peat depth	Probe rods
8. Peat density	Nuclear density meter

Data	Measurement Technique
9. Peat moisture content	Nuclear moisture meter
10. Mat depth and composition	Inspection, sample analysis
11. Drawbar pull	Load cell, recorder
12. Slip, speed	Fifth wheel, recorder
13. Trim angle	Tiltmeter, recorder
14. Pressure under track	Pressure cell
15. Torque output at sprocket	Torque meter
16. Number of passes	Count
17. Rolling resistance	Calculation
18. Sinkage, sinkage rate of vehicle	Level, targets
19. Sinkage, sinkage rate under a standard load	Level, targets

Items 11, 12, 13, 14, 15, 16, 17 and 18 will be noted as the vehicle travels along the test lanes. The remaining data will be gathered from the test lanes before traffic or adjacent to the test lane, as required.

DATA REDUCTION AND ANALYSIS

A period of time will be necessary (approximately 6 weeks) for data reduction and analysis. This will include editing the 16-mm. film and examining the data according to the following hypotheses:

1. Sinkage rate for a standard load is proportional to water content.

2. Net sinkage for a standard static load is proportional to diameter and number of woody and non-woody fibers in the mat.

3. Rolling resistance is proportional to sinkage/rate/unit load pressure, weight of vehicle, number of road wheels, track width, pressure variation amplitude along track length.

4. There is a relation between drawbar pull, slip, and muskeg type, as described by quantitative specifications for a given vehicle.

REPORT PREPARATION

A draft report will be prepared as a result of the data analysis and will be submitted to the Defence Research Board Project Directorate by 31 August, 1966. It will form the foundation for a final report following consultation between OATRU and the Defence Scientific Information Service.

A final report will be submitted to the Chairman, Defence Research Board by 30 December, 1966 and, as required by the statement of work, will include:

1. Results of terrain and course surveys in appropriate tabular or graphic form;

2. Quantitative and qualitative results of the vehicle operations and an analysis of results;

3. A comparison of results where possible, with the results of previous trials;

4. An analysis of the relation of design concept to mobility or lack thereof;

5. Photographs depicting specific results of vehicle operation and examples of physical terrain and course features;

6. A 16-mm. colored film strip, with description notes suitable for the insertion of a sound monologue, covering high points and special features of the summer's operations.

COMPLETION OF REQUIREMENTS OF STATEMENT OF WORK

The plan of test is designed to satisfy the requirements of the DRB statement of work. The extent to which this can be accomplished will depend on availability of vehicles, unforeseen delays due to breakdowns or immobilization of vehicles, breakdown of instrumentation, prevailing weather conditions, and the possibility of accidents involving equipment damage and personnel injury. The contractor (OATRU, McMaster University) should not be held responsible for failure to accumulate data or perform tests for any of the above reasons.

Furthermore, failure to accumulate data may have some effect on later analysis of the data, and this fact should be recognized for contract purposes.

ANTICIPATED MAJOR DIFFICULTIES

Anticipated major difficulties have been noted in the above section. As these difficulties cannot be specifically planned for, they must be dealt with as they arise. It is therefore to be understood that the proposed plan of test will not necessarily be rigidly adhered to from the point of view of timing or data acquisition. In the event of failure to complete tests or acquire data, an account of such failure and the reasons for it will be provided in the report, and the Contractor shall not be held in default under the terms of the contract.

In the event of departure from the plan of test, the program shall proceed in a manner mutually agreed upon by the co-operating parties involved (i.e. OATRU, DRB, DDP, AEEE).

APPENDIX II

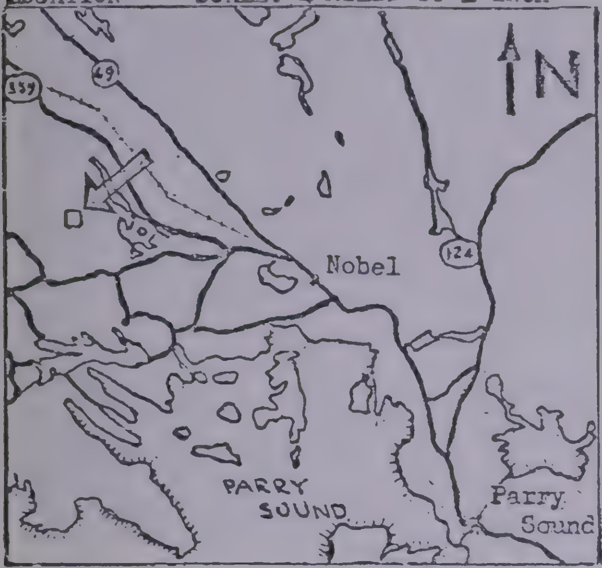
TERRAIN DESCRIPTION

TERRAIN DESCRIPTION

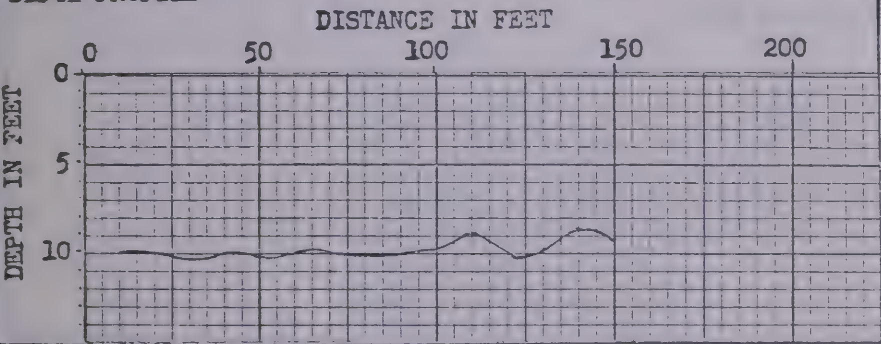
AREA: Thousand Acre Bog
COVER: EI
WATER REGIME: High(Very wet)

ROUGHNESS: 2.0 IN.
AVERAGE CONE INDEX: 0"-6" 24
6"-12" 30
12"-18" 36

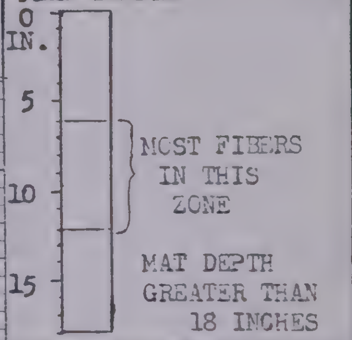
LOCATION SCALE: 4 MILES TO 1 INCH



DEPTH PROFILE



PEAT SAMPLE



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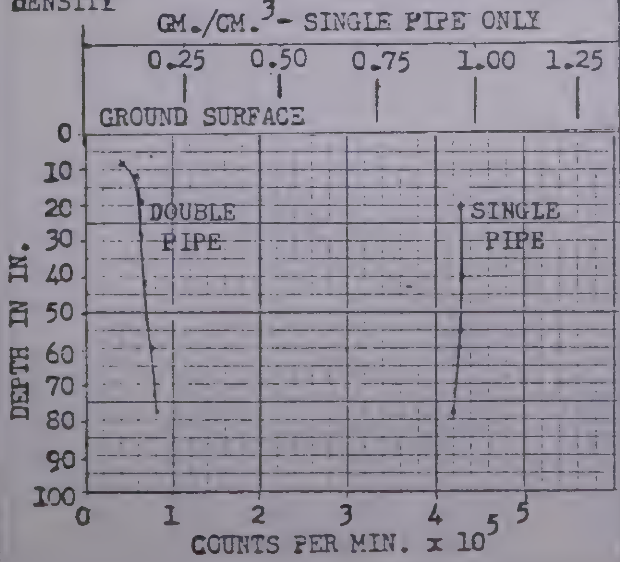

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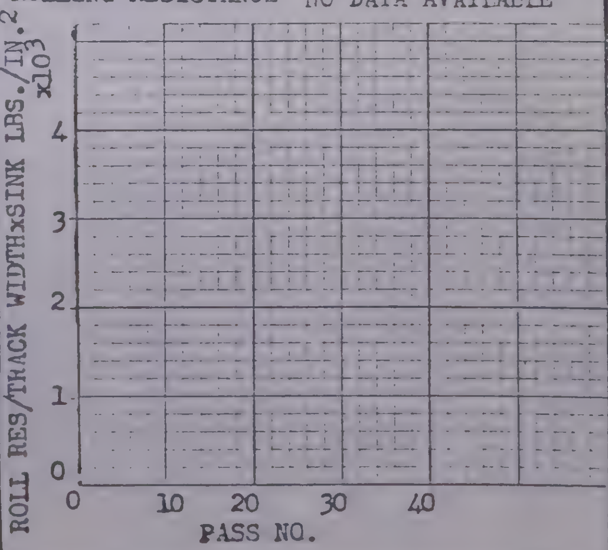
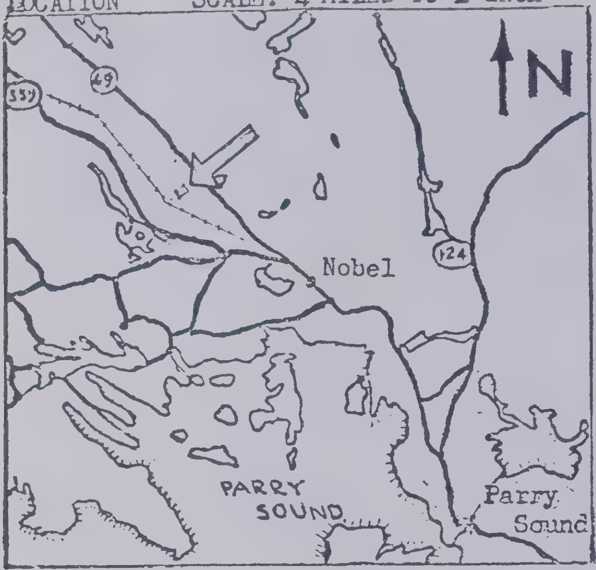


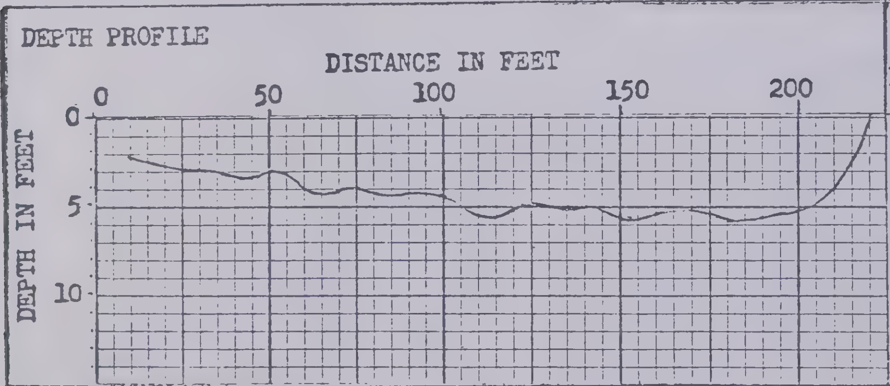
TERRAIN DESCRIPTION

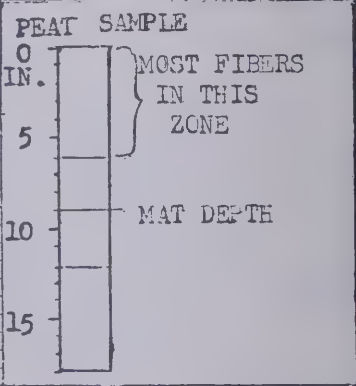
AREA: 10A
COVER: EI
WATER REGIME: Medium (Moist)

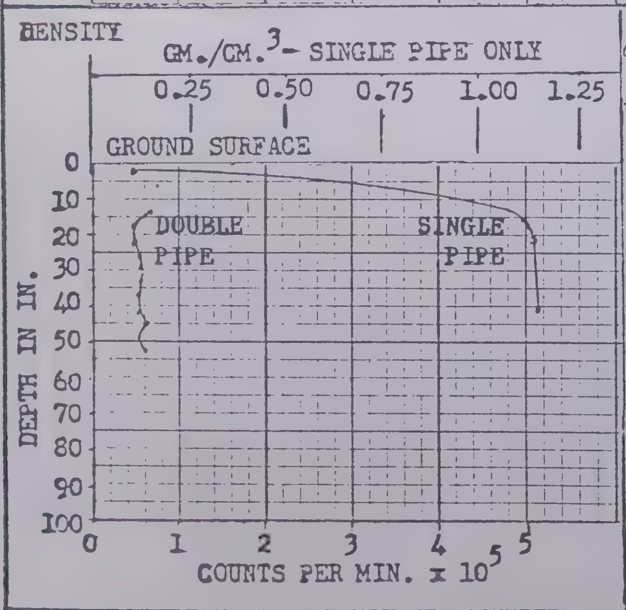
ROUGHNESS: 1.8 IN.
AVERAGE CONE INDEX: 0"-6" 30
6"-12" 40
12"-18" 48

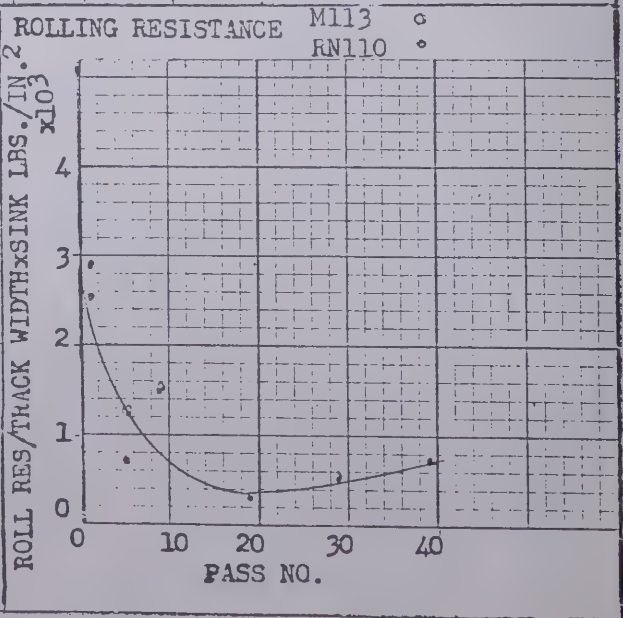
LOCATION SCALE: 4 MILES TO 1 INCH









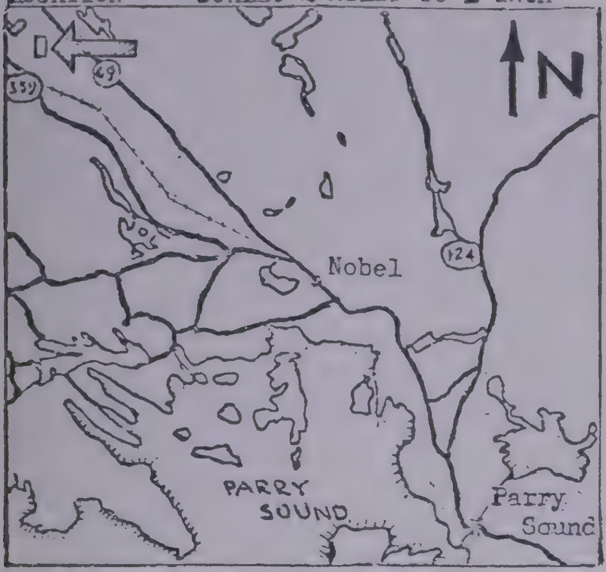


TERRAIN DESCRIPTION

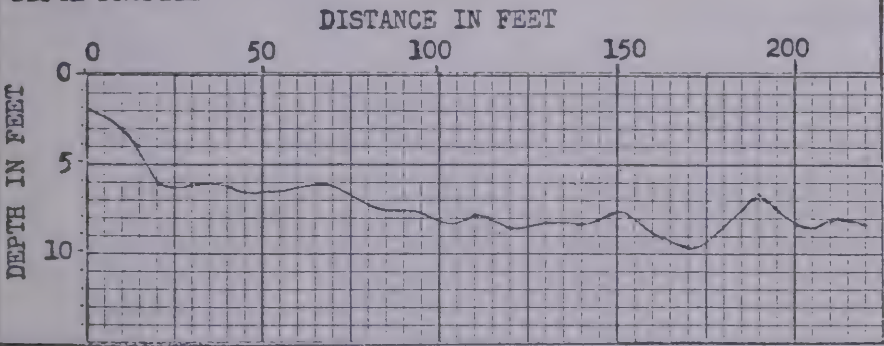
AREA: Woods
COVER: EI
WATER REGIME: Low (Dry)

ROUGHNESS: 3.0 IN.
AVERAGE CONE INDEX: 0"-6" 27
6"-12" 37
12"-18" 45

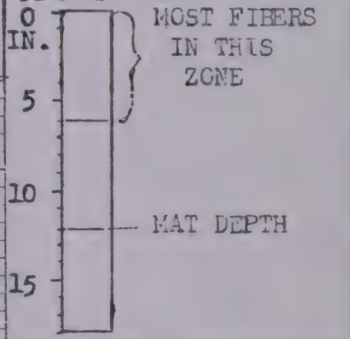
LOCATION SCALE: 4 MILES TO 1 INCH



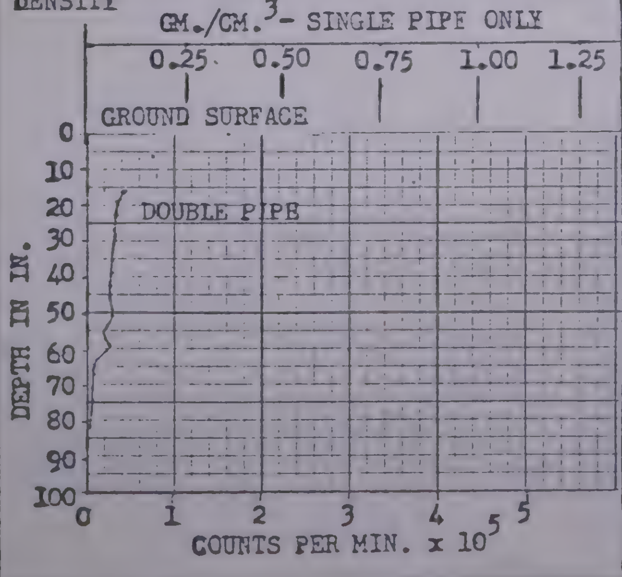
DEPTH PROFILE



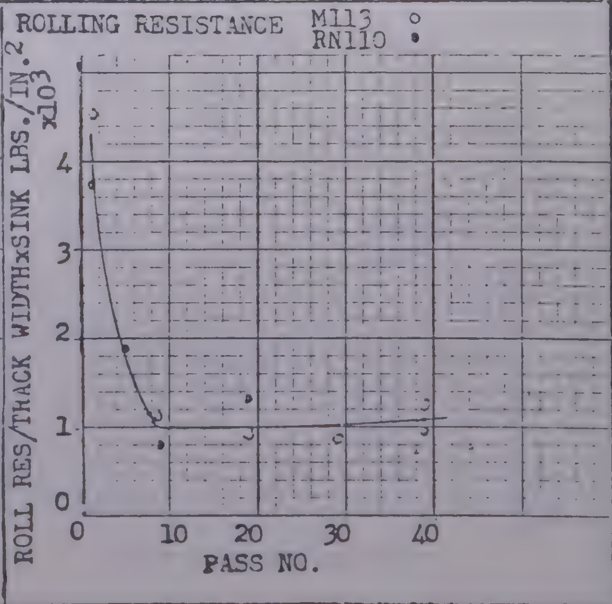
PEAT SAMPLE



DENSITY



ROLLING RESISTANCE

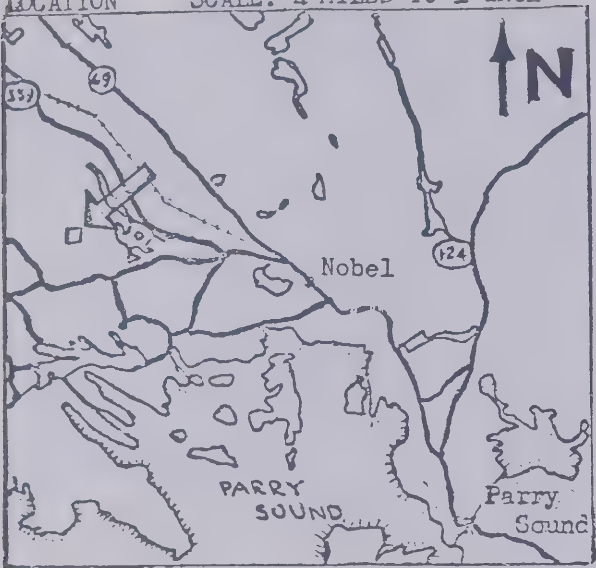


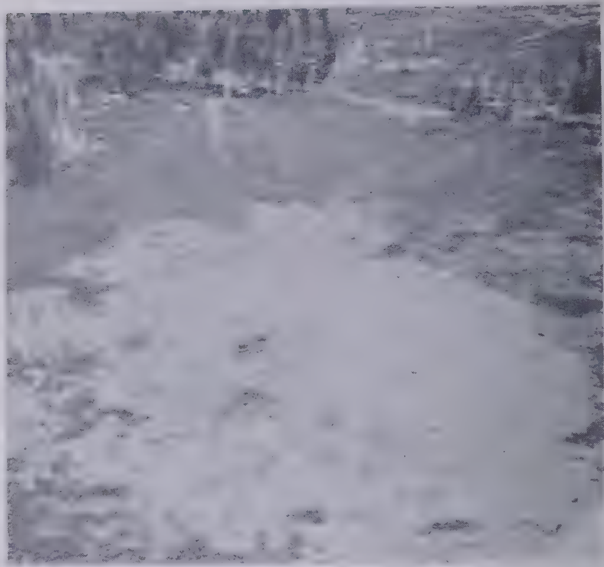
TERRAIN DESCRIPTION

AREA: Thousand Acre Bog
COVER: FI
WATER REGIME: High (Very wet)

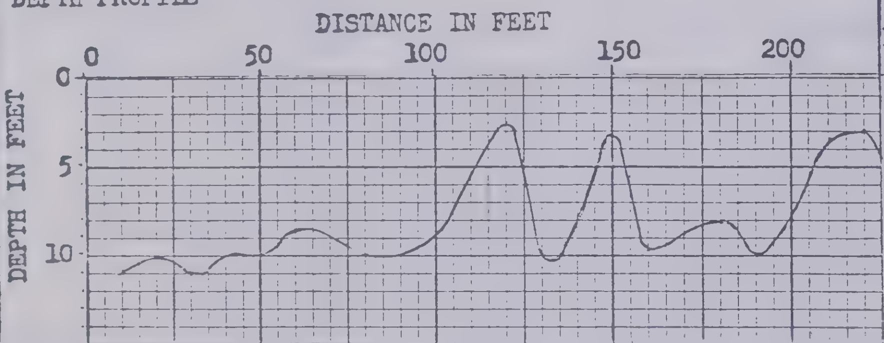
ROUGHNESS: 1.9 IN.
AVERAGE CONE INDEX: 0"-6" 23
6"-12" 23
12"-18" 30

LOCATION SCALE: 4 MILES TO 1 INCH

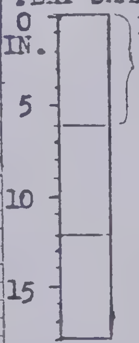




DEPTH PROFILE



PEAT SAMPLE



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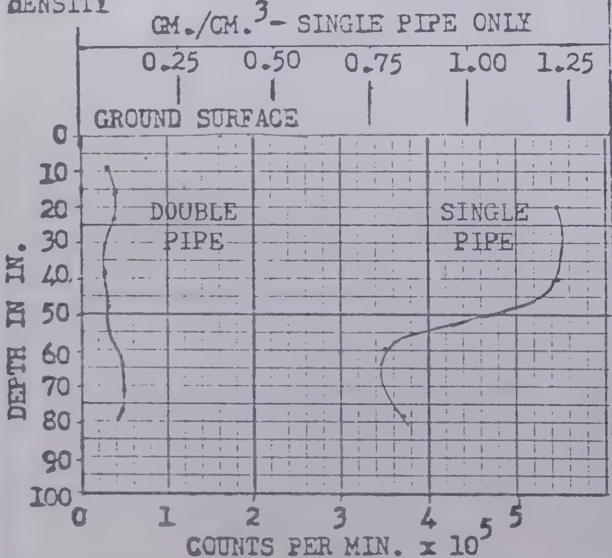

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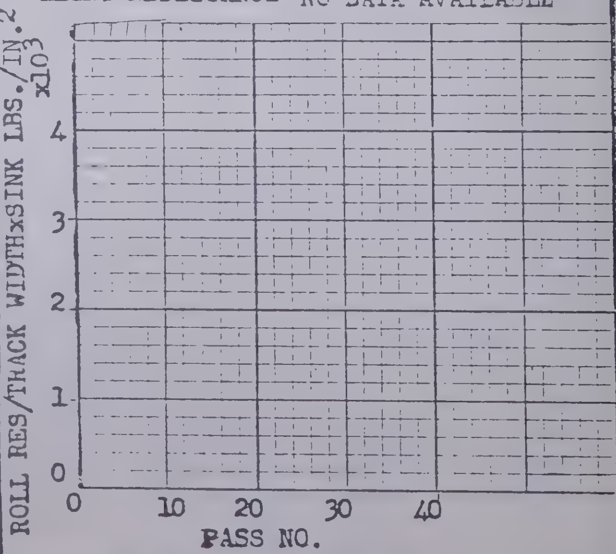
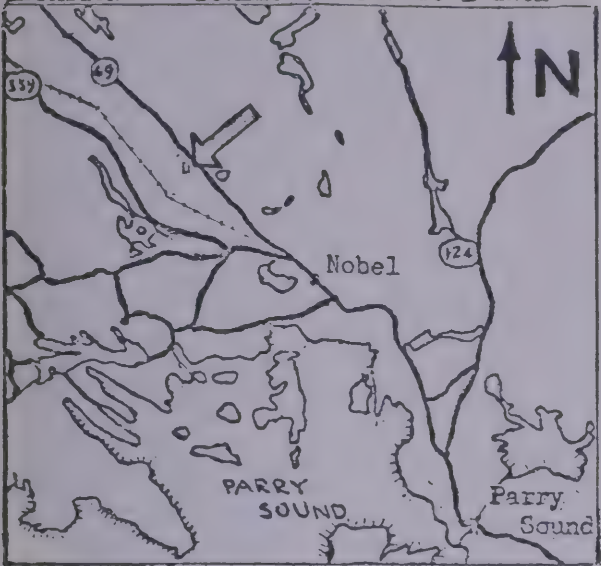


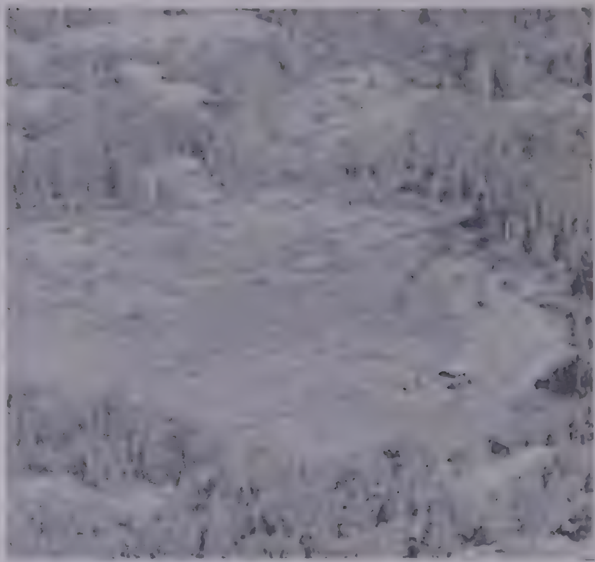
TERRAIN DESCRIPTION

AREA: 66-1
COVER: FI
WATER REGIME: Medium (Moist)

ROUGHNESS: 1.0 IN.
AVERAGE CONE INDEX: 0"-6" 34
6"-12" 52
12"-18" 52

LOCATION SCALE: 4 MILES TO 1 INCH





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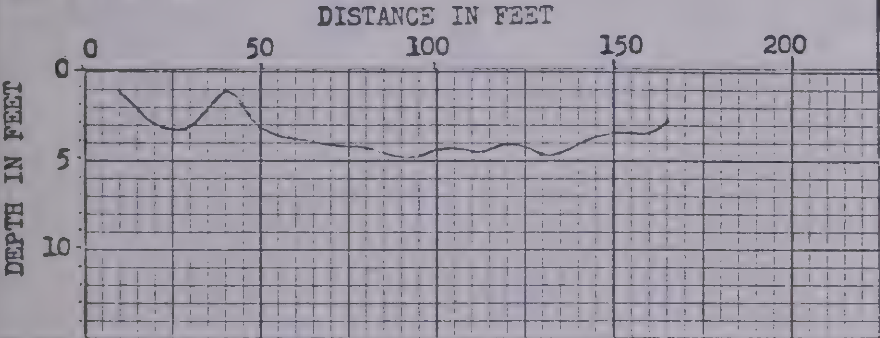
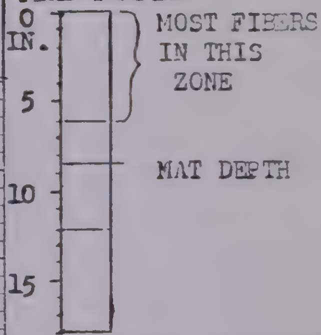


PEAT SAMPLE



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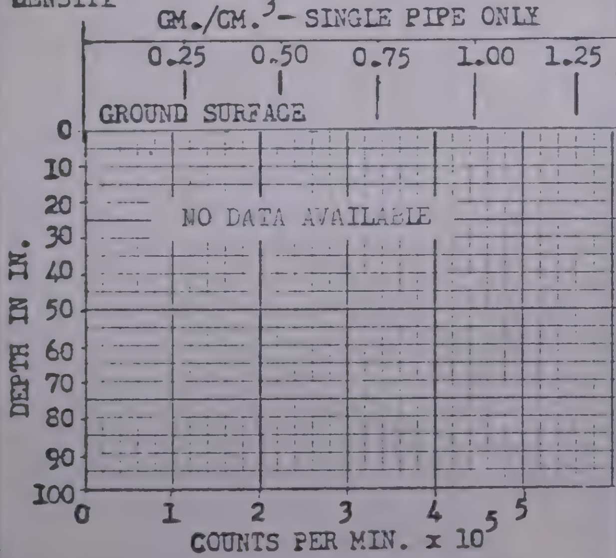

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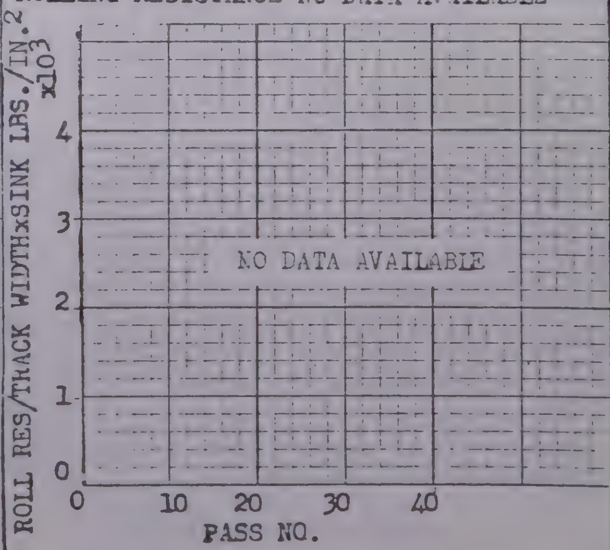
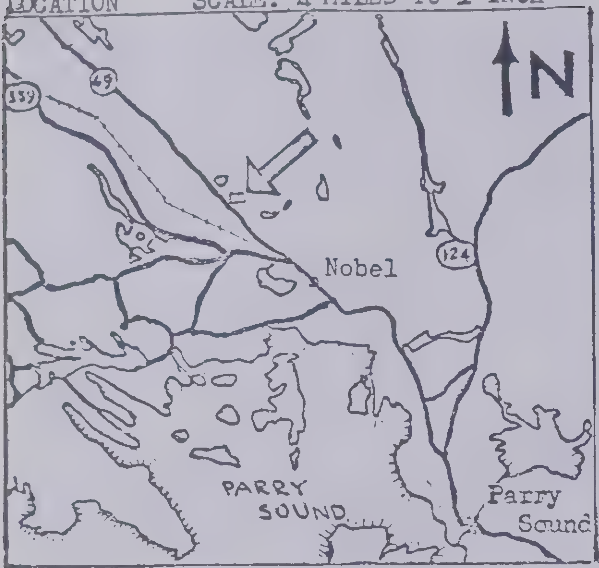


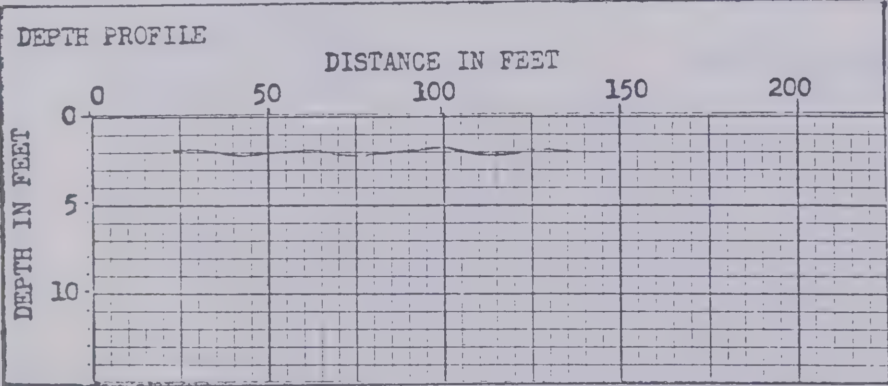
TERRAIN DESCRIPTION

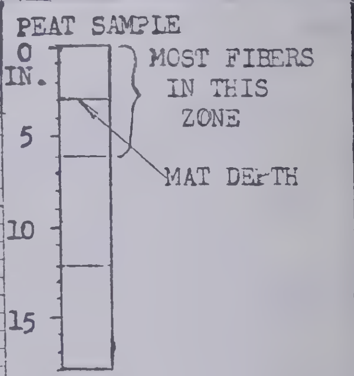
AREA: 7
COVER: FI
WATER REGIME: Low (Dry)

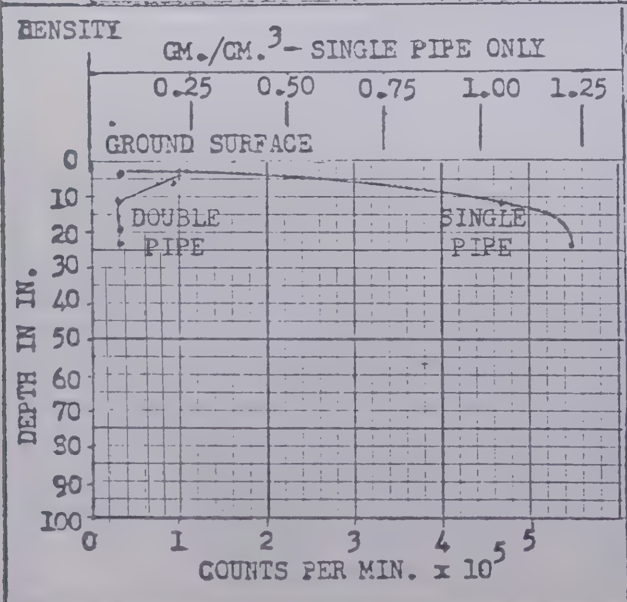
ROUGHNESS: 1.1 IN.
AVERAGE CONE INDEX: 0"-6" 43
6"-12" 46
12"-18" 51

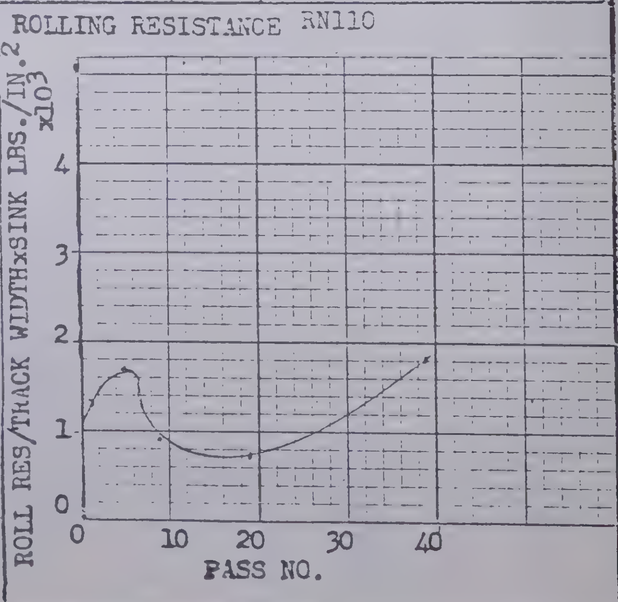
LOCATION SCALE: 4 MILES TO 1 INCH











APPENDIX III

VEHICLE PERFORMANCE

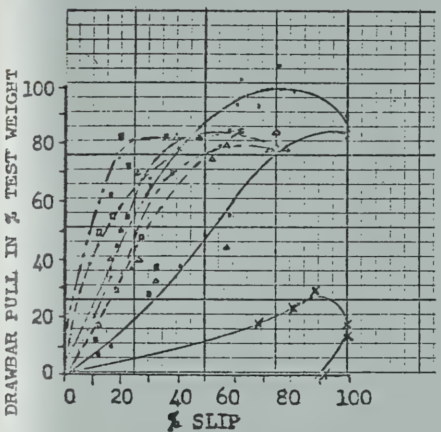
VEHICLE PERFORMANCE

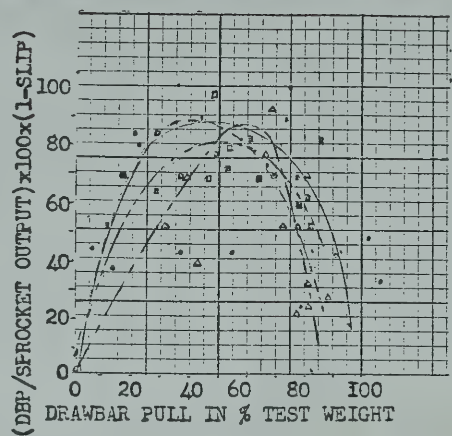
SPECIFICATIONS:

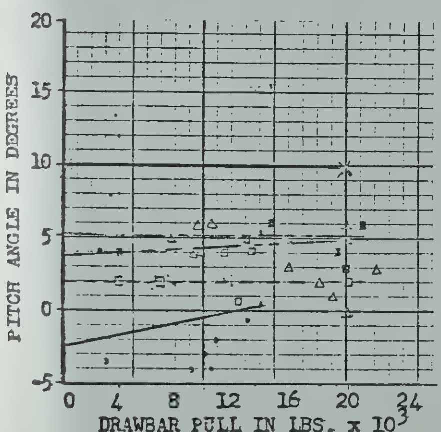
Vehicle	Nodwell RN110
Test Weight	24500 LBS.
Track Width	40 IN.
Track Length	136 IN.
Nominal Ground Pressure	1.8 P.S.I.
No. of Road Wheels	4/TRACK
Sprocket Diameter	22 IN.
Hard Ground Rolling Resistance	700 LBS.

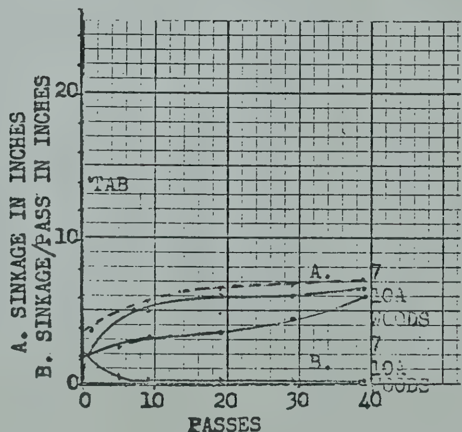
DRAWBAR PULL LEGEND (1ST PASS ONLY)

Hard ground	•	————
Thousand Acre Bog (TAB)	×	————
Woods	□	- - - -
10A	△	— — —
7	■	— - — - —









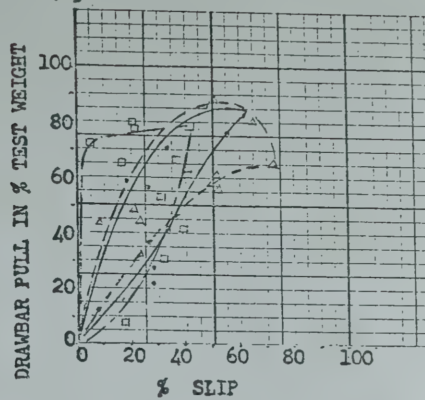
MULTIPASS DRAWBAR PULL

VEHICLE: NODWELL RN110

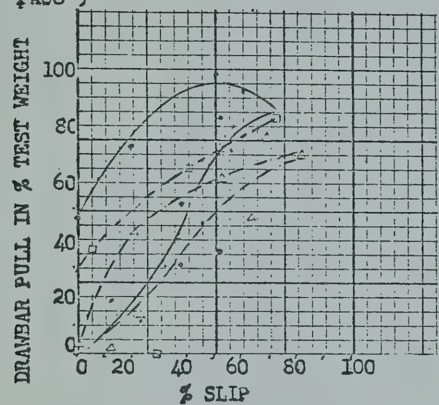
LEGEND

AREA	COVER		
Woods	EI	————	•
10A	EI	- - - - - - -	△
7	FI	— · — · —	□

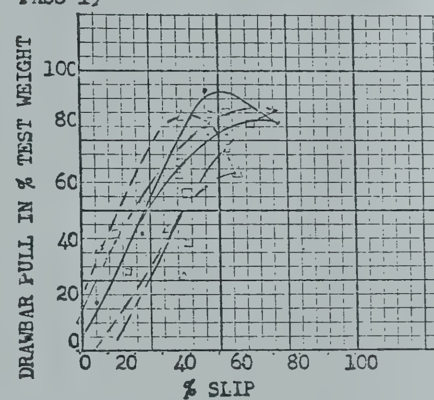
PASS 5



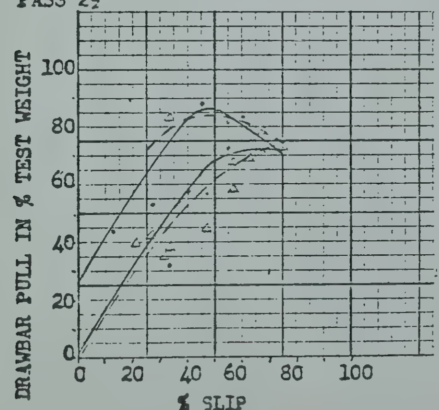
PASS 9



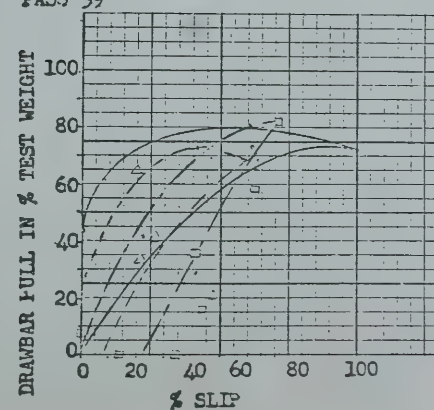
PASS 19



PASS 29



PASS 39



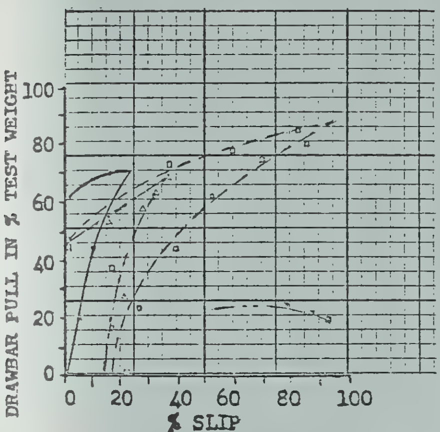
VEHICLE PERFORMANCE

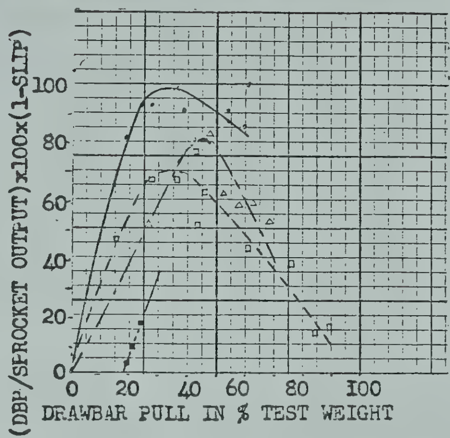
SPECIFICATIONS:

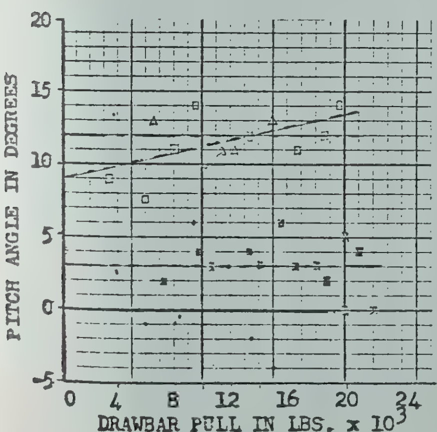
Vehicle	M113
Test Weight	22000 LBS.
Track Width	15 IN.
Track Length	109 IN.
Nominal Ground Pressure	6.8 P.S.I.
No. of Road Wheels	5/TRACK
Sprocket Diameter	20 IN.
Hard Ground Rolling Resistance	700 LBS.

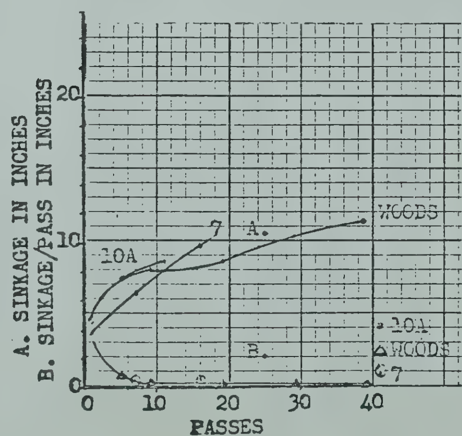
DRAWBAR PULL LEGEND (1ST PASS ONLY)

Hard ground	•	———
Woods	□	- - - -
10A	△	— — —
7	◪	— - - —









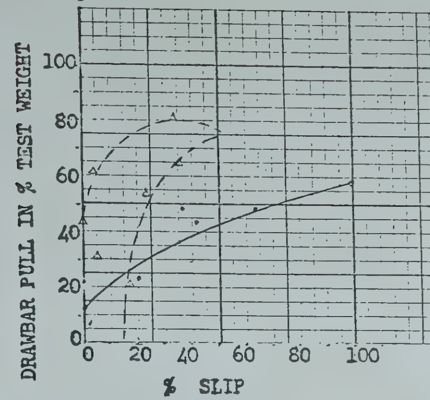
MULTIPASS DRAWBAR PULL

VEHICLE: M113

LEGEND

AREA	COVER		
Woods	EI	———————	•
10A	EI	- - - - - - - -	△
7	FI	—·—·—·—	□

PASS 5



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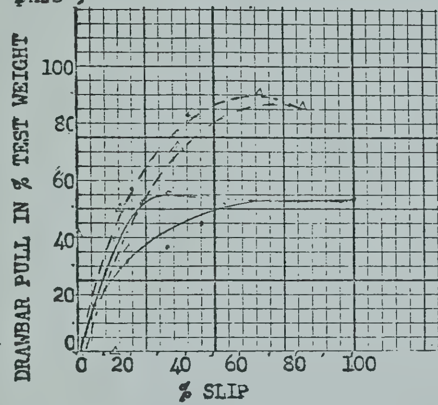

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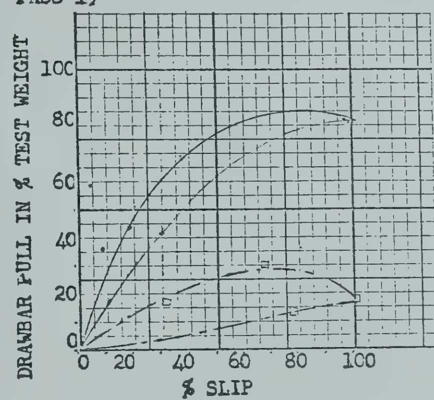

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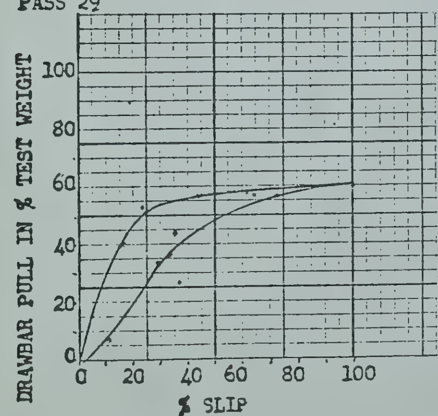
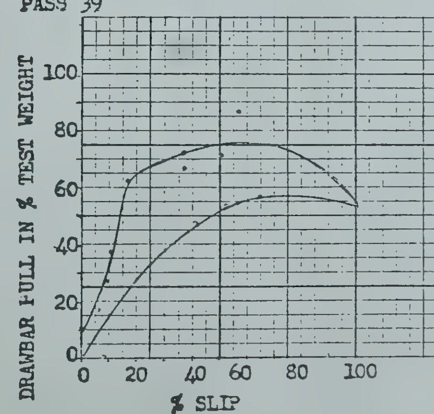


PASS 39



APPENDIX IV

NOTES ON DEPARTURES FROM PLAN OF TEST

NOTES ON DEPARTURES FROM PLAN OF TEST

Owing to breakdowns and unavailability of equipment from time to time during the trials, it was sometimes necessary to depart from the Plan of Test with respect to both scheduling of the trials and procurement of some measurements. As required by the Plan of Test, an account of these departures and the reasons for them are given here.

TERRAIN MEASUREMENTS

Peat Density

There was insufficient time available prior to 22 July, the official end of the trials period, to obtain density data in several areas. After that date, measurements were obtained in most of the areas using OATRU's CL61 Rat to transport the density measurement equipment. However, before data were obtained in area 66-1, the Rat suffered a broken track, which could not be repaired adequately with the times, materials, and facilities available. The density measurement equipment is not hand portable, and therefore no means were available for carrying it to area 66-1.

Peat Moisture Content

Originally, it was intended that, to measure moisture content, a fast neutron source would be used with the scaler in a manner similar to that used to measure density. A fast neutron source had been ordered, but was not available until several weeks after the field program had been completed. For this reason, no data on actual percentage moisture content of the test areas are available and visual observation was used to assess moisture content on the basis of relative amounts of free water present on the ground surface.

VEHICLE PERFORMANCE

Pressure Distribution in Peat Under Vehicles

Only one pressure cell and a small portable recorder were available for this measurement. The cell frequently became damaged by a vehicle digging it out of the ground as a result of high track slip, and the recorder was suffering from some undetermined disorder, so that in the end it was not possible to obtain any pressure cell measurements in these tests.

Completion of Tests

The Plan of Test provides for procurement of data in a total of 6 test areas. Vehicle performance data were not obtained in the Thousand Acre Bog FI and EI and Area 66-1, for reasons already described under "Measurement Techniques and Observations – Vehicles".

Fig. 1. Load cell and fifth wheel used for drawbar pull and vehicle speed measurement.

Fig. 2. Mounting hole for torque measurement strain gauges in RN110 axle.

Fig. 3. Slip rings for torque measurement.

Fig. 4. Hollow axle extension for mounting slip rings.

Fig. 5. Slip rings mounted on M113.

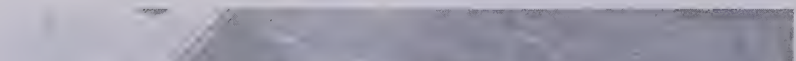


Fig. 6. DC generator for track speed measurement mounted on M113.

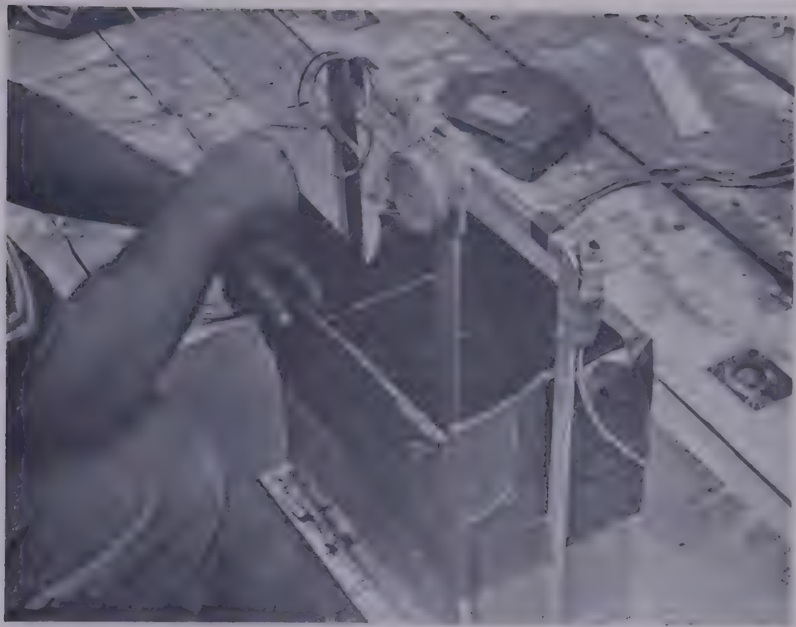


Fig. 7. Pitch angle transducer.

Fig. 8. Sinkage measurement target mounted on M113.

Fig. 9. Zero reference target for sinkage measurement.

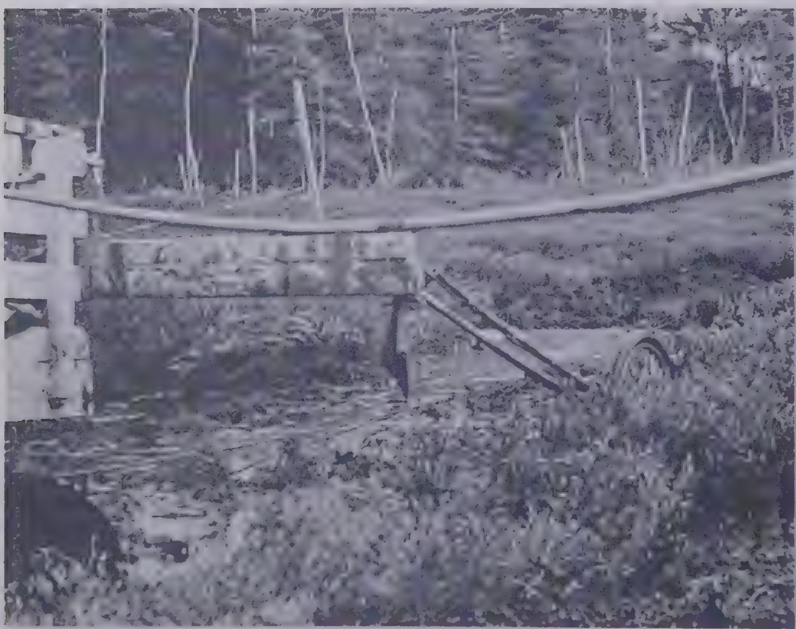


Fig. 10. Mounting bracket for fifth wheel on RN110.

Fig. 11. Sinkage of M113 in Thousand Acre Bog EI.

Fig. 12. Sinkage of RN110 in Thousand Acre Bog EI.

F . 13. Torn wiring on RN110 after operating in Thousand Acre Bog EI.

Fig. 14. Field operation of oscillograph chart paper processor.

Fig. 15. Broken road wheel spindle from RN110.

Fig. 16. Hard ground rolling resistance measurement on RN110.

Fig. 17. Broken end of axle extension shaft.

Fig. 18. Replacement of axle shaft extension of RN110.

Fig. 19. RN110 operating in dry EI.

Fig. 20. RN110 operating in moist EI.

Fig. 21. M113 operating in dry FI, Area 7.

Fig. 22. M113 immobilization in dry FI, Area 7.

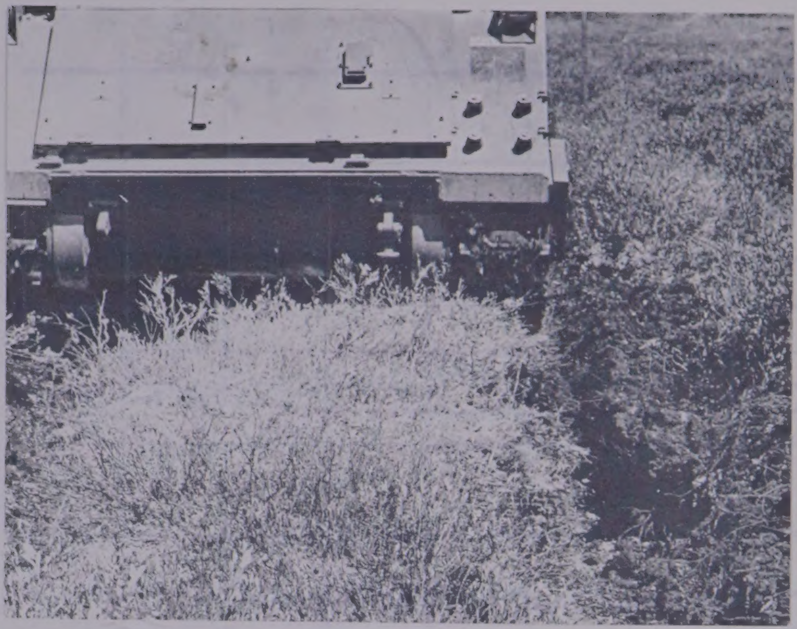


Fig. 23. M113 rut depth in Area 10A, moist EI.

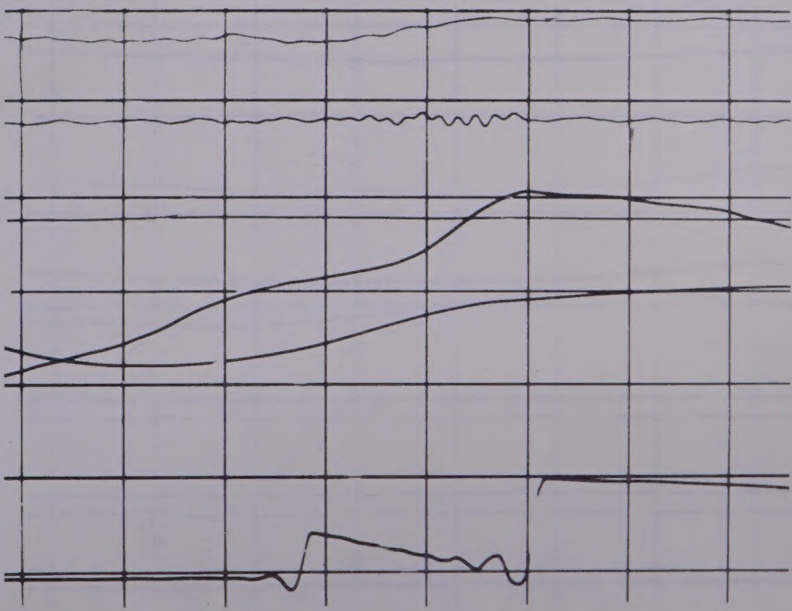


Fig. 24. Lower trace shows drawbar pull during tow cable break in RN110 test Woods Area, dry EI.

Fig. 25. Two wave-like traces represent torque oscillation in M113 drive axles.

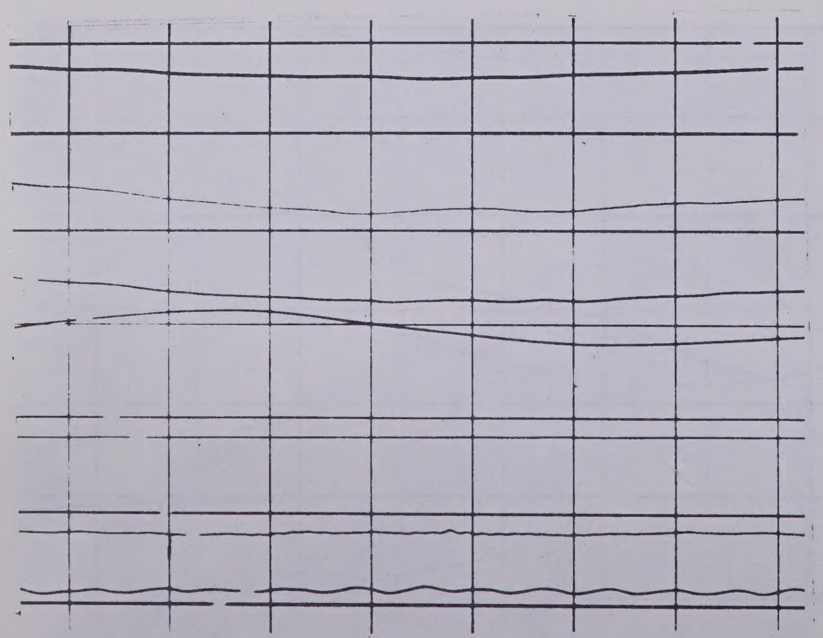


Fig. 26. Central low frequency sinusoidal trace illustrates slow response and under-damping of pitch angle transducer.